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Integrative Problem-Solving in a Time of Decadence

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To the little girl of Damascus

Foreword

> *The stages of development have been run through. Institutions function painfully. Repetition and frustration are the intolerable result. Boredom and fatigue are great historical forces.*
>
> Jacques Barzun

Let me say at the very outset that readers who are convinced that they are right about all matters of human inquiry, having no doubts whatsoever, probably do not need to read this book. They should, nevertheless, be reminded of Albert Camus' quote: "Those who claim to know everything and to settle everything end up killing everything." Instead, the book hopes to appeal to those problem-solvers, in the broad sense, who think "outside the box;" who develop the skill of thinking about the solution of a problem rather than merely advance the skill of searching for it;[1] who possess a certain level of *esprit de finesse* in addition to analytical thinking and, hence, they would appreciate some flavor of philosophy, psychology, literature, history, and art embedded in the interpretation of their formal scientific tools. This integration of seemingly remote and disparate intellectual domains produces fertile interactions that could be a source of inspiration for fields in a state of limited conceptual advancement and creativity. As such, the book is critical and provocative rather than neutral and encyclopedic, and should be of interest to those who are willing to consider that all is not well with the system within which they operate.

It should not escape the reader's attention that the book was written during a time of *Decadence* that characterizes every aspect of the society (politics, economics, culture, art, science, and education). A time of deep concern, confusion, and peculiar restlessness; a time of intellectual decline, superficiality, diminishing meritocracy, and decreasing social mobility; a time of pseudo-pragmatism and highly valued consumptionism, when the powers that be focus on agenda-driven policies at the expense of human principles; a time of post-truth political and social

[1] In the Internet, commercial toolboxes, and the like.

environments in which arguments are merely operational than fact-based; a time of vulgar corporatism characterized by deep-rooted corruption, greed, and institutionalized deception; a time of radical deconstruction and ahistoricism; a time of hostility to major intellectual traditions and human achievements of the past; a time of the disappearance of significations, and the almost complete evanescence of values in favor of an increasingly meaningless world; a time of devaluing and even cheapening both humankind and Nature without any serious protest; a time of crisis that is not only out there in the world, but primarily in Man's[2] own consciousness.

In higher education one witnesses the negative effects of the *unholy alliance* of financial corporatism and radical postmodernism (undermining tradition, knowledge, language, and achievements of the past; promoting nihilism, and seeking to satisfy lower needs). As a result, the university is unable to prepare students for the most critical element of life in the twenty-first century: the largely *unknown* yet potentially catastrophic consequences of the considerable slowing down of material growth and prosperity due to climate change, economic globalization, international competition, and instability. Changes linked to material growth (industrial pollution, diminishing resources and the like) impose unavoidable restrictions on the *status quo* worldwide, including people's standards of living, consumerism obsession of western societies, and the monomaniac focus on perpetual economic growth. It is highly uncertain that the crucial issues emerging from these restrictions worldwide can be resolved with democratic procedures.

It is not that there is not sufficient activity during the time of Decadence. On the contrary it is often an active time period, but effort and energy are largely misdirected, there are no clear lines of advance, and no sense of *possibility*. No doubt, there is plenty of action, for example, in terms of government think tanks, agenda-driven institutional panels, and self-congratulatory committees. But this is mostly action without introspection and deeper thought, which makes it like shooting without aim. Many of these committees are what Richard Harkness identified as groups of unwilling individuals, chosen among the unfit, to do the unnecessary. In this respect, relevant is the old Greek proverb: *'Οσοι δεν σκέπτονται, συσκέπτονται* (i.e., those who cannot think, co-think). Alas, this uninspiring social climate that favors blind action and keeps human intellect thus subordinate is the same climate that characterized the pre-Enlightenment era.

The above happen on the surface of the societal domain. But deeper under the surface, widespread cynicism, ruthless utilitarianism, and a prevailing sense of meaninglessness dominate most sectors of the society. In essence, it is hard to find the environment of intellectual refinement and freedom of thought that could facilitate the emergence of the fertile and inspiring genius of a Michelangelo, an El Greco (Doménikos Theotokópoulos), an Immanuel Kant, a Johann Wolfgang von Goethe, a Charles Darwin, a Miguel de Cervantes, a Fyodor Dostoevsky, a Henri Poincaré, a Niels Bohr, or a Bertrand Russell. This kind of geniuses not only

[2] For the scholarly reasons discussed in Barzun (2000: 82–85) the word "Man" is used throughout the book in the sense of human being(s) of either sex.

do not exist today, but they are not even conceivable in the current corporatism era dominated by what has been called the *Greediest Generation* (Pizzigati, 2004; Kristof, 2005): the generation of people who consumed the abundance that was built by their parents and took passive profits at the expense of their children. This is a generation which, unlike earlier generations (Brokaw, 1998), has every reason that many of its actions be forgotten, which is perhaps why it has embraced the ahistorical outlook of postmodernism.[3]

Arguably, two distinct elements characterize the *dynamics* of any given phase of civilization: the momentum generated by past achievements, and a strong sense of prospect and possibility. We are in a phase of Decadence that is disproportionately dominated by the former rather than the latter element. Most people prefer to live comfortably in a material world and to operate mechanically or self-unconsciously within the landscape created by others, letting those others decide about them – before them. Experience is mostly sensual, and there is no time for inwardness, and seeing through the mind's eye. The commodification of even humans implies that humanity can exist as a mere factor of production measured in monetary terms, which is a societal model that has detracted from authentic well-being and created an amoral or even immoral system. No doubt, we live in times that try people's souls. Which means that there are no innocent bystanders. Exempting oneself from the struggle against the forces of Decadence, and pretending that the struggle one witnesses is not really one's concern, is the highest expression of irresponsibility.

In view of the above considerations, this book builds its case through integrative discussions of science, mathematics, philosophy, education, epistemology, and the quest for a genuine inquiry process. Thus, the book is concerned with the development of a framework of *integrative problem-solving* (IPS) that encourages and enhances the investigator's individual characteristics and differences in the spirit of what may be called *non-egocentric individualism*. This is the state of delivering one's values and purpose without being self-centered in value thinking. In non-egocentric individualism one experiences human inquiry in the way one experiences Byzantine hymns: As a unique fusion of heavenly melody and intellectual depth.

Engaging the higher cerebral fractions for less than a second, the author came up with the term *Epibraimatics* to denote the use of epistemic ideas and principles (*Epi*) from brain sciences (*brai*) to develop action-based mathematics (*-matics*) for the solution of real-world problems under conditions of multisourced uncertainty and composite space–time dependency. It is then a fundamental premise of Epibraimatics that an IPS approach, designed to fit neuropsychological functions shaped during many years of evolution, should be more creatively and efficiently implemented by the human brain than conventional approaches that do not account

[3] In the words of Thomas L. Friedman (2010) this is the generation that has "eaten through all that abundance like hungry locusts," so that the next generation of young people has been dubbed *Generation Debt*.

for these functions. Epibraimatics' aim, at a minimum, is to lay bare some of the relevant IPS issues that have been hidden by the mainstream answers.

The considerations above express a change of perspective. First, while it is commonly assumed, and justifiably so, that a sound knowledge of physical sciences is a crucial prerequisite for a deeper understanding of the sciences of living organisms, the opposite can be also valid: the understanding of a physical system and the solution of the relevant problems can be affected in a fundamental way by the agent's[4] knowledge of mental functions and brain activities. Second, Epibraimatics should be distinguished from other scientific inquiries that also study the brain's structure and patterns, but with different objectives, such as building intelligence machines or developing computer architectures that are syntactic engines rather than semantic ones. In fact, the prime concern of Epibraimatics is not whether computers think but *whether people do*. Third, Epibraimatics does not seek to copy physical brain activities (how neurons interact, cell functions etc.),[5] but rather to develop IPS methods that best fit important mental functions of a well-rounded investigator. In other words, while it is surely very important to understand how a brain made purely of material substance somehow gives rise to mental functions characterizing an agent's experience, the primary focus of Epibraimatics is the mental functions themselves and how they are involved in IPS, and not how exactly they arose from physical brains. In this sense, Epibraimatics focuses mainly on the "software" of the human brain rather than its "hardware."

To achieve its goals, Epibraimatics revisits vital concepts and notions of problem-solving, and emphasizes their contextual meaning and implementation in the IPS milieu. It directly introduces basic theoretical considerations in the quantitative study of natural systems (physical, biological, social, or cultural). In the process, it raises a number of important questions regarding the term "problem–solution" and its meaning from different viewpoints: physical, mathematical, philosophical, and psychological. Therefore, instead of the dry presentation of a problem–solution technique within a hermetically sealed mathematics discourse,[6] one focuses on the basic inquiry process that investigates the problem's conceptual background and knowledge status, and presents it in a methodological setting that accounts for "world-agent" interactions, and introduces mathematical tools in an environment of realistic uncertainty. This change in perspective implies that scientists who wish to accomplish their educational and research goals on occasion may need to approach their work in a *literary* way, as well.

It has been said that often the road to understanding is *via negativa*: Much of learning is done through unlearning of what is established yet outdated. In this spirit, Epibraimatics suggests revisiting certain unreflective views about

[4] Herein the term "agent" will refer to a rational human being.

[5] Like neural networks do, for example.

[6] Indeed, many theorists tend to wrestle much more with technical issues than conceptual ones and, whenever possible, they transform the latter into the former.

problem-solving and replacing them with a novel vision of what really constitutes a solution of a real-world problem. In such a context, some of the ideas in the book may have a postmodern flavor, whereas several others are critical of radical post-modernism. This is hardly surprising, for two reasons: postmodernism is what Glenn Ward calls a "portable" term, lacking a unique and solid definition (what postmodernism means in one discipline may not be compatible with what it means in another); and the synthesis of different thinking styles and knowledge sources is, in fact, an essential ingredient of the book's philosophy. The book constantly reminds its readers that, postmodernist or otherwise, one should always remember that the "paradises" created by human minds are almost always destroyed by the hard realities of human nature.

The crux of the matter then is that the existing cracks in the conventional interpretation of the term "problem–solution" could let the light shine directly on the mysteries of human inquiry and account for the conceptual seeds and the formulation of theoretical ideas that are compatible with in situ reality. The winners of the twenty-first century will be those who will realize first that conventional thinking cannot solve most of the complex problems of the modern world. It is becoming increasingly clear, indeed, that this sort of problems demand much more than mainstream thinking allows.

The above considerations are of significant value, since in many cases of corporate research and institutionalized development, instead of intellectual debate the focus is solely on the exchange of technical opinions and disciplinary trivialities. Critical thinking is often replaced by an almost uncontrollable urge to obtain the latest and reassuringly expensive experimental devices and to use the most computationally demanding techniques. In a very real sense, many researchers *are* what equipment and techniques they use.[7] It is, thus, hardly surprising that the *clerkdom* of the ruling elites and self-serving power holders dominating many aspects of the enterprise cannot tolerate intellectual depth, whereas it strongly favors professions lacking introspection. Accordingly, the book's prime criticism of the clerkdom focuses on its astonishing absence of vision concerning the dramatic changes underway that will greatly affect the future of science and education in the twenty-first century, as well as the well-being of the society at large. A critical re-assessment is needed of the worldview dominating today's affairs. This is a most serious task that cannot be accomplished by the mentally and anthropologically aged clerkdom. Surely, it is not the first time that research and education, in particular, are facing serious challenges. However, today's challenges emerge in a post-meltdown world (Read 2009),[8] where considerably fewer resources are available, highly praised (and costly) policies have failed miserably, a striking lack of political leadership is noticed in countries facing

[7] In a similar way that many people *are* what they eat, as the irresistible rise in obesity in USA signifies.

[8] Here, of course, I refer to the financial meltdown of 2008 and its devastating consequences worldwide.

huge social problems, traditional political and cultural powers of the West lose much of their influence, and new powers emerge. In sum, the "rules of the game" are changing fast worldwide.

Τα πάντα να τα εξετάζετε, το καλό κρατείτε[9] wrote Apostle Paul, in an obvious effort to emphasize the importance of considering critically all different things in life and create a *synthesis* of the best among them. Accordingly, another compelling reason to oppose the clerkdom's influence is its stern opposition to creative synthesis and the serious damage this opposition causes to human inquiry. The anti-synthesis attitude of the clerkdom is observed not only between different disciplines. Even within the same discipline the consideration of perspectives other than the one favored by the discipline's elite are not welcomed. For example, the manner young investigators with brilliant ideas that do not serve the elite's agenda are treated by the funding bureaucrats resembles the way the Shuar people of the Upper Amazon Basin used to shrunk heads in order to imprison "evil" spirits. Because of its vested interests in a specific worldview, the clerkdom discourages people from obtaining a sense of how one discipline or field relates to all the others, and so makes it impossible to appreciate the ultimate ingredient of human inquiry: the synthesis of different thinking modes and belief systems aiming at a balance between divergent or even opposing proposals, to draw out and combine that which is valuable in each. This creative synthesis is at the heart of Epibraimatics.

Reflecting to these and similar considerations, an IPS approach would introduce three methodological premises concerning the real-world inquiries of noble thinkers who are characterized by their mental finesse rather than mere technical expertise. The first premise is that the *search* for Truth (i.e., the ever-changing process of inquiry by means of which this ultimate goal is sought) is as important as Truth itself. In fact, the former is an absolutely realistic endeavor, whereas the latter may escape the human capabilities. This crucial distinction has escaped the attention of many radical postmodern studies in their rush to attack the possibility of truth, and embrace irrationality and a far too passive "anything goes" perspective. If history is any guide, the search for truth has been an instrumental component of human inquiry. During the searching process, science's real contribution has always been to provide partial yet useful *representations* of Nature and solve important problems based on these representations.[10] With time the existing representations are replaced by new and improved ones, in the sense that the latter are able to offer better explanations of observed phenomena, obtain unexpected results, and generate more accurate and informative in situ problem–solutions.[11] This process of incrementally coming to grips with the real-world situation

[9] "Prove all things, hold fast that which is good." First Epistle (**5**:21) of Paul the Apostle to the Thessalonians.

[10] Due emphasis is given, e.g., to the fact that natural models are imperfect representations of reality rather than reality itself.

[11] The idea of a scientific process that increasingly approximates the truth has its philosophical roots in the tradition of the Eleatic thinkers Xenophanes and Parmenides (sixth and fifth century BC).

(characterized by the uncertainty of the agent's epistemic situation, the possibility that things are not the way they appear to be, and the uncomfortable yet constructive feeling of wonderment inspired by the human failure to reach the ultimate Truth) is a vital element of human inquiry. Correspondingly, starting with the high goal of seeking objectivity, one can substantially improve the final outcome of the inquiry, even if this outcome is in the end a subjective assessment of reality.

The second premise is that most of today's real-world problems cannot be solved within the boundaries of a single scientific discipline. Instead, these problems have an essential *multidisciplinary* structure, which means that their successful study transcends disciplines and requires a synthesis of vocabularies from several of them. In which case, the only way to arrive at a meaningful solution of the problem is to integrate thinking modes, concepts, techniques, and data from all these disciplines. In a multidisciplinary study, each participant must contribute something different, significant, and original – because in order to understand someone, you must be someone.[12] Multidisciplinarity does not cancel the individual characteristics of each participating discipline. On the contrary, it encourages and enhances individual characteristics and differences in the spirit of non-egocentric individualism. Last but not least, the focus of a multidisciplinary study often is an open system (which refers to science as a basis for action) rather than a closed one (usually associated with curiosity-based scientific research).

The third premise concerns the decisive role of the *human agent* in both deriving the problem–solution and recognizing the process leading to that solution. Human agents have been particularly effective at knowing about the world in terms of cognitive representations of aspects of the world that are important for their survival. Therefore, an IPS approach: (a) involves mental functions of brain activity, including an intended purpose with an intelligible value and subsequent adaptation caused by the "mind (internal representation)-problem (external structure)" interactions and the evolving environment of the problem; (b) is conditioned by the agent's epistemic situation concerning the problem, including the relevant knowledge bases (core and site-specific), beliefs (causal and otherwise), background, and even prejudices; and (c) accounts for the fact that the data gathered are in many practical cases incomplete and inaccurate, which make uncertainty assessment and data reliability two key elements of the IPS process.

In the Epibraimatics milieu, the brain may be viewed as a machine operating in terms of a "cause–effect" scheme, whereas mind may be seen as an artist trying to realize an idea. When it comes to original problem-solving, the human brain can be far more powerful than any mechanical device and computer. In order to learn from important mental functions and use this knowledge as an inspiration to develop a meaningful IPS framework, Epibraimatics takes an interest in what goes on inside the two-sided human brain as well as in the observable and measurable behavior combined with cognitive technology. As was postulated above, one plausibly

[12] This means to *really be* someone, not just *pretend to be* someone, as so often is the case nowadays.

expects that such an IPS approach should be implemented more efficiently by the brain than the conventional approaches, for it is designed to fit the brain's evolutionary features.[13] Conventional approaches do not account for these features. Instead, they reflect what our current mathematical tools are capable of handling.

Socrates regarded ideas as the "currency of thoughts." In a Socratic framework, Epibraimatics emerges as the fusion of ideas and functions from different fields of inquiry. This fusion can include, *inter alia*, an interpretation of neuropsychological ideas and functions in a way that can be very fruitful in IPS and the quantitative study of natural systems. This effort yields a set of conceptual postulates and the corresponding mathematical operators. The postulates have an evolutionary flavor, i.e. they evolve as new core knowledge and site-specific data become available, whereas the clarity, richness, and detail provided by the operators are some of their main attractions. In the same setting, the goal of IPS is not merely to accumulate new knowledge but to understand the meaning of this knowledge. In other works, the investigator should not only focus on *how* a solution works (*operational* IPS component), but also on *why* the solution works (*substantive* IPS component). On occasion, the latter may imply thinking in a literary way about scientific problem-solving.

To understand a concept or a method, the process of inquiry must be able to look at them in many different ways, and to interpret and connect them to related concepts and methods. This is a prime element of the Epibraimatics strategy, which is why this book suggests looking at the main IPS components from different perspectives. Only by interpolating between the full range of disciplines and the associated thinking styles can an investigator arrive at a satisfactory account of in situ problem-solving. The argumentation mode an investigator uses is a crucial ingredient of scientific inquiry, in general, and IPS, in particular. It can restrict the statement of the problem, the questions that can be asked concerning the problem, and the solutions that can be obtained. An improved reasoning mode may lead to a re-statement of the problem that brings the investigator suddenly up against the deepest questions of knowledge. For this to happen, in some cases one needs to operate beyond critical reasoning in the realm of *creative thinking* that blends form and content in an indivisible whole.

Mature scientific disciplines are characterized by a close tie between science and philosophy, which includes weaving the philosophical tapestry into the mathematical formalism. As far as the most fundamental scientific theory is concerned, every quantum physicist can confirm that, no matter where one looks, one is always led back to philosophy. According to Philipp Frank, "When we examine the most creative minds in 20th century science, we find that the greatest ones have strongly stressed the point that a close tie between science and philosophy is indispensable." This happens because, like all human practices, different sciences have their own presumptions (conceptual, methodological etc.). The role of philosophy is to bring these presumptions to critical scrutiny, clarify ideas, and remove misunderstandings,

[13] Brain itself is a product of evolution, thus the characterization "evolutionary."

a role that amply demonstrates the high practical value of philosophy as proposed by Immanuel Kant and Ludwig Wittgenstein, among others. Broadly speaking, Epibraimatics assumes that successful practices in many scientific fields require a clear idea of what is presupposed in what one does, which is why it involves an integrated framework of scientific-philosophical inquiry. This integration is in agreement, on the one hand, with the view that science provides a powerful means to understand the natural world and human beings as part of this world. Philosophy, on the other hand, is able to contribute to what on its face might otherwise appear to be an entire scientific issue by helping to test and reshape intuition, frame the right questions, and gain a better understanding of the key concepts that are driving the solution of a problem. The integration can also resolve certain misconceptions. An example is the distinction between natural truth and its mental representations. A stone has a physical reality (e.g., an agent can experience the stone by holding it, kicking it, or being hit by it), but it also has several mental representations (in the sense that one may view the stone as a building material, as a weapon, as a way to hold a door open etc.).

Yet, for all its sophistication our knowledge encounters sharp limits that arise from the paradox that we *who* observe are part of *what* we are trying to comprehend. Furthermore, space–time heterogeneity and uncertainty (conceptual and technical; ontic and epistemic) characterize in situ existence. For these reasons, Epibraimatics does not exclusively express itself in deterministic mathematics as its "native language." Depending on the problem under investigation, one may trace a "foreign accent" in mathematical arguments, which introduces a probabilistic formulation of the reasoning at work in various parts of the IPS process. This formulation is called *stochastic reasoning*, and its objective is to establish the all-important dialectics of randomness (multisourced uncertainty) and necessity (space-time causality in the broad sense). The term "stochastic reasoning" is used without implying a major new field of theoretical mathematics. Rather, stochastic reasoning's attraction lies in perceiving the conceptual structure of problem-solving in an uncertain, context- and content-dependent environment. Underlying context sensitivity, e.g., is the assumed regularity of justifiable action: *ceteris paribus*, investigators act in whatever way is best justified given their epistemic condition and in situ reality. The concepts and techniques of stochastic reasoning are relevant, powerful, and useful in deriving meaningful solutions of the emerging complex in situ problems. The probability notion (with its various interpretations) is of vital importance in the study of in situ situations. Probability is not a purely intuitive science, in which case we should be ready to rethink what we had intuitively accepted before. Experiencing stochastic reasoning is not about withdrawing from the world into rational abstraction, but rather the constant cultivation of open sensory awareness that blends abstract thinking with physical insight. The Epibraimatics' proposal includes an appropriate balance between intuition and evidence-based rationality. This balance may require that the mathematical equations of probability calculus be considered in a new light, and presented in a way motivated by the needs of knowledge synthesis and agent-reality interaction, as well as by a sense of aesthetics. In this setting, stochastic reasoning underlines the conceptual and methodological importance of deep theory in scientific inquiry. While its formulation has a mathematical life of its own, stochastic reasoning accounts for and is constrained by concepts of brain and neuropsychological sciences as well as by the philosophical worldview embedded in IPS in the broad sense.[14] This is a rather natural outcome, due to the multidisciplinarity of real-world problems, the multi-sourced uncertainties characterizing their solution, and the different thinking modes of the agents involved.

In view of the above discussion, Epibraimatics may be of limited use in the imaginary world of deterministic mathematics, where everything works with unrealistic perfection and mechanistic accuracy, and prediction is certain. Instead, Epibraimatics is absolutely relevant in the *action-based* study of real-world phenomena and systems, where various sources of incomplete information are present, space-time dependency is of fundamental importance, and accurate prediction is far from being a certain affair. In such an environment, the feelings of awe, veneration, and wonder inspired by the ineradicable uncertainty of human knowledge about Nature can turn out to be powerful constructive forces.

So far we have merely outlined the book's proposal toward an IPS framework that accounts for different kinds of influence (uncertainty sources, auxiliary conditions, space–time change, and "agent–Nature" interactions). The main points, stated very compactly above, will become clear as our story unfolds. And so too will my own views and even prejudices about the matter of human inquiry. Whatever the case may be, my sincere effort has been to provide the readers with well-researched and well-documented arguments. Naturally, several thinkers have exerted key influence upon the ideas presented in this book. Although one cannot exclude the possibility that in certain cases this influence might be grounded on my misunderstanding of some of their views. If this is true, I hope that the misreading has been a productive one.

In many ways, the book is a call for introspection and research rather than a finished project. As such, the book makes an attempt to reach the minds of readers who think of something more than the appetites of the hour. Like any book of this kind, the present one acknowledges that not only must certain ideas be explained, but readers' previous schooling may need to be overcome. In this effort, the book would give the impression that it is written in a characteristic form of polemics with an imaginary opponent. But this is not intended to be an impolite book, even if Francis Crick once said that, "Politeness is the poison of all good collaboration in science." Book writing should not be viewed as a public relations affair (flattering the elites, subscribing to fashionable views, and making influential friends), but rather as a principled matter (providing the means to express oneself, promote continuing dialogue, and generate constructive debate).

[14] In other words, the readers of this book should expect a considerable number of concepts, metaphors, interpretations, and insights, and not merely a routine presentation of formulas and equations.

Admittedly, in certain ways this is an unusual book. But, it is not a dry book with sterilized opinions carefully stated not to annoy the current dogmas and established views. Instead, it is a book with colorful opinions, provoking metaphors and analogies, and sometimes unusual syntheses of concepts and ideas from diverse fields. The book invites the readers to adopt Seneca's motto: *Dum inter homines sumus, colamus humanitatem.*[15] Accordingly, a prime issue is honest communication and not that the readers necessarily agree with my views, interpolations, and conclusions. As far as I am concerned, what really matters is that the book offers the readers an opportunity to meditate on a number of topics that I happen to consider important and, hopefully, so do the readers. Marcus Valerius Martialis once said: *laudant illa*, *sed ista legunt*, i.e. some writing is praised, but other is read. I will be satisfied just with the latter option.

The book salutes the *noblemen and noblewomen of thought*[16] whose perpetually inquisitive minds resist the attacks of the clerkdoms of institutionalized research and corporate science, and they sacrifice a lot in the process. Noblemen and noblewomen of thought do not just report science but, most importantly, they assess it critically and with mental finesse. They are committed to guarding the *Thermopylae* of "The true, the good, and the beautiful" against the barbaric attacks of the established clerkdom and its self-serving elites. These elites, on the other hand, are mute in their souls – intellectual challenge and disagreement rarely arise among their ranks. As such, they represent a pathetic epoch, which, in its impotence to create or recognize something really new, has been reduced to rehashing aged[17] ideas and processes that is not even truly capable of knowing and bringing to life.

In the current phase of Decadence, clerkdom's influence on human affairs has become a major pollutant of the will, the soul, the mind, and the imagination. Experience shows that as soon as the clerkdom's shadow epistemology becomes part of the culture of a field (scientific or otherwise), this is the beginning of the end of this field, as far as intellectual innovation and creativity are concerned. Therefore, the clerkdom threatens the essence of human inquiry and makes its practice no longer enjoyable. If the clerkdom prevails completely, we should all migrate to Mongolia to raise chickens.[18]

Having said all that, I would like to conclude as I started. Ultimately, the book is addressing those real-world problem-solvers who would appreciate some flavor of philosophy, history, psychology, and art embedded in the interpretation of their

[15] That is, "as long as we are among humans, let us be humane."

[16] These include scholars and intellectuals who appeal to creative imagination as a source of evidence, convey their thoughts in different media, and see things from multiple viewpoints transcending the boundaries of specific disciplines, without losing their ability to evaluate these things both individually and as a whole.

[17] Here, the meaning of the term "aged" is that used in Martin Heidegger's description of his visit in Venice (Heidegger 2005: 6): "Aged was everything and yet not exactly old; everything belonged to the past and yet not to a past that still continues and gathers itself into something remaining so it can give itself anew to those who await."

[18] This comment is attributed to Ludwig Wittgenstein.

mathematical tools and scientific skills. Those who do not welcome such a broad perspective but, instead, prefer the apparent safety and convenience of the Cavafian "walls" raised around them by a certain discipline or established system, may want to return the book to the shelves; and rest assured, life will pass by like Heraclitus' ever-changing river.

San Diego, California George Christakos

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Contents

Chapter 1
The Pursuit of Knowledge

In the course of his inexplicable existence, Man bequeathed to his descendants multiple evidence, worthy of his immortal origin. As he also bequeathed vestiges of the dawn's remnants, snowballing celestial reptiles, kites, diamonds and glances of hyacinths. Amidst moans, tears, famine, lamentations and cinder of subterranean wells.

N. Gatsos

1.1 Crossing the Gate of Night and Day

"Dare enter the world of Knowledge!" With these words the goddess addressed Parmenides who had just crossed the *Gate of Night and Day*. This part of Parmenides' Poem *On Nature* offers a powerful metaphor of humankind's unended quest: The "Night" represents the world of ignorance and error, and the "Day" represents the world of knowledge and truth.

The pursuit of knowledge has always been Man's way of becoming aware of his natural environment, and a central component of his ageless struggle to understand the world around and inside him. Since ancient times, knowledge has been instrumental in harmonizing human life with the great forces of Nature and, at the same time, a crucial tool of problem-solving and survival in an environment of significant complexity, uncontrollable changes, unexpected developments, and hidden dangers. In the seventeenth century, Francis Bacon summed it all up in his famous quote: *Ipsa scientia potestas est* (knowledge is power). The Baconian motto implies that Man needs to know in order to act adequately under exterior compulsion or in accordance with inner necessity.

The onus of *integrative problem-solving* (IPS) requires the intensive and extensive combination of knowledge and skills associated with distinct areas of human activity. Accordingly, in their effort to study real-world problems and understand Nature, people are increasingly expected to skillfully synthesize knowledge from different sources and under conditions of in situ uncertainty. To gain a deeper understanding of IPS, it is appropriate to review these different sources of knowledge and their historical development.

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1.1.1 The Path from the Wise Men to the Internet

Basic means of knowledge include perception, memory, consciousness, and reason. Knowledge acquisition, storage, and transmission have always been a collective pursuit. Faced with the need to solve the daunting problems of life on Earth, early Man was engaged in the process of gaining knowledge, sharing it with his fellows, and passing it on from one generation to another. This was done, first orally: in tribes the so-called wise men were memorizing common store of knowledge and were guardians of tradition. And then in writing in the form of clay tablets, papyruses and books stored in libraries. This was a major development in human history.

1.1.1.1 Hospitals of the Soul

The earliest public libraries were created around the seventh century BC by the people of Mesopotamia and Anatolia (Sumerians, Babylonians, Assyrians, and Hittites). Well known is the library of *King Ashurbanipal* at the Mesopotamian city of Nineveh, which included 25–30,000 clay tablets written in cuneiform. They contained information on a variety of items concerning history, religion, poetry, administration, and medicine (Frahm 2004; Frame and George 2005). Arguably, the greatest of all libraries of the ancient world was that of the city of *Alexandria* in Egypt founded by the Ptolemies at the beginning of the third century BC (Casson 2001), also known as *Ψυχής Ιατρειόν* (Hospital of the Soul). The library included halls with shelves (known as “bibliothikai” or *βιβλιοθήκαι*) for placing the 650,000 scrolls and acquisitions, cataloguing departments, lecture and reading halls, meeting and dining rooms, walking colonnades, and gardens. Other very important libraries were those of *Constantinople* during the Byzantine times. The First Imperial library of Constantinople, which was founded by the emperor Constantius II, is estimated to have contained about 100,000 volumes of ancient text. Legendary was Baghdad’s *Bayt al-Hikma* (House of Wisdom) founded in the 8th AD century by caliph Abu Jafar al-Mansur, which included a library with thousands of books, a translation bureau, and an academy of scholars and intellectuals from across the Abbasid empire (Lyons, 2010).

As is often the destiny of intellectual heritage from the dawn of civilization to modern times, these libraries became the prime target of all kinds of anti-intellectual forces. In 391, the Christians destroyed an annex of the great library of Alexandria, and in 640 the leader of the Arab forces that had conquered that city ordered the burning of the main library.[1] Similar was the fate of the libraries of Constantinople. They weathered the storm for many centuries more, including major damages inflicted by the knights of the Fourth Crusade in 1204, until the city fell to the Turks in 1453.

[1] Allegedly, the officer on duty in the destruction of the library of Alexandria used two stamps with which he marked the papyruses. One stated: “Does not agree with the Koran – heretic, must be burned.” The other stated: “Agrees with the Koran – superfluous, must be burned.”

1.1.1.2 Plato's Academy and Aristotle's Lyceum

During Man's everlasting effort to cross the *Gate of Night and Day*, gaining *practical* knowledge has been part of his everyday activities and contact with Nature (searching for food, building a shelter, and cultivating the earth). On the other hand, *theoretical* knowledge (meaning of life, search for truth, and moral issues) has been systematically pursued in specific places, like universities and research institutes.

According to John L. Tomkinson (1999), Isocrates founded the world's first university in Athens near the beginning of the fourth century BC. This was followed shortly afterward by Plato's *Academy* and Aristotle's *Lyceum*, both also in Athens. In these two schools, the first known research libraries were set up and linked to the pursuit of new knowledge and innovative problem-solving. Writing about Plato, Ralph Waldo Emerson (1892: 41) asserted that, "Out of Plato come all things that are still written and debated among men of thought." According to James Garvey (2006: 17), "Aristotle. . .is an intellectual anomaly. His genius seems inexplicable. It is difficult to believe that a single human mind could have done so much." The ideas, theories, and solutions developed in the schools of Plato and Aristotle concerning major issues of human existence and meaning greatly influenced people's thought and action for many centuries, and they continue to do so during modern times. It is noteworthy that, among many other things, it was Aristotle who invented the idea of a *discipline* and even proposed a number of specific disciplines by bringing into being the organized study of physics, metaphysics, biology, mathematics, logic, meteorology, politics, psychology, rhetoric, poetry, ethics, aesthetics, and theology.

1.1.1.3 From Euripides to Pier Paolo Pasolini

Since Ancient times, *theater* has been another influential means for transmitting knowledge, expressing social concerns, and educating the citizens. The theatrical plays of Euripides, Aeschylus, Sophocles, Aristophanes, and others, not only entertained the ancient Athenians, but also made them aware of important social, cultural, and political problems within their own city and even outside it. *Mutatis mutandis*, similar was the role of *cinema* during the twentieth century. To quote the pioneer director Jean Renoir (1974: 11),

> In my view cinema is nothing but a new form of printing – another form of the total transformation of the world through knowledge.

During its best phases, cinema incorporated human inquiry in a sophisticated process of creative expression that benefited people's intellectual development and search for meaning in life. In this process, many ancient theatrical plays have been presented in a movie form and assigned novel interpretations. A characteristic example is the 1969 movie *Medea* of Pier Paolo Pasolini based on Euripides' classical drama with the opera singer Maria Callas in the leading role. The public lives through how myth offers a vehicle for people in a given culture to understand

and deal with their own life's experiences. Pasolini interpreted Euripides' play as a clash of two diametrically opposed cultures: Ancient and sacred versus modern and profane. In this sense, the movie can be viewed as a parable for disastrous encounters between civilizations (e.g., West and the Third World).

1.1.1.4 From Pope Gregory I to Pablo Picasso

Different kinds of visual and mnemonic aids of knowledge acquisition and public education have been used through the centuries. The Gothic churches and cathedrals of Europe were covered with hundreds of *statues* and *carved figures* that presented a compendium of biblical characters and stories (Von Simson 1988). In the seventh century, Pope Gregory I (the Great) wrote:

> To adore images is one thing; to teach with their help what should be adored is another. What Scripture is to the educated, images are to the ignorant . . . they read in them what they cannot read in books.

This was a key declaration that essentially acknowledged that the *images* can serve the uneducated, the majority of the population who knew only the vernacular language and nothing of the official Latin of the Church. For many people living in the medieval times, a visible image represented an invisible truth indeed.

Likewise, a *painting* generates new knowledge that could greatly influence the way people look at certain aspects of life. For example, in his path-breaking 1907 painting *Les Demoiselles d'Avignon*, Pablo Picasso creatively employed the notion of four-dimensional space to respond to the dramatic changes sweeping across Europe during the early twentieth century. The painting conveyed to the public a completely new outlook on modern art, and is widely celebrated as a cornerstone of modernism (Plagens 2007). Another visual aid to knowledge representation and communication is offered by *maps* of various kinds and shapes. Such maps are generated by means of a range of simple or sophisticated techniques, depending on the situation. For example, the selected maps of Fig. 1.1 represent expertly assessed and integrated multidisciplinary knowledge about the space–time distribution of Black Death mortality in fourteenth century Europe, using state-of-the-art mapping concepts and techniques. Various other kinds of maps can be found in the relevant literature (see, e.g., Taylor 2002; Virga and Library of Congress 2007).

1.1.1.5 The Internet, and Epistemic[2] Cultures

From a certain perspective, the role of the wise men, libraries, etc., as knowledge sources is played today by the *Internet*. Indeed, many people see the Internet as a

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[2] Generally, the term "epistemic" refers to the construction of models of the processes (perceptual, intellectual, and linguistic) by which knowledge and understanding are achieved and communicated. According to some scholars, the term "epistemic" has its origins to Aristotle's *Nichomachian Ethics*.

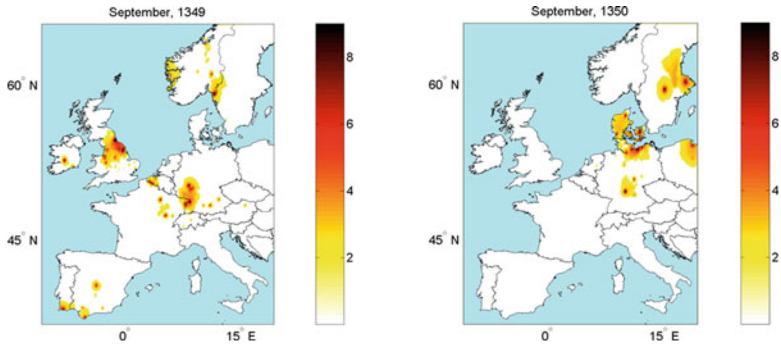

Fig. 1.1 Selected space–time maps of monthly Black Death mortality rate (%) in fourteenth century Europe (Christakos et al. 2007)

place to store and share knowledge, thus allowing fruitful communications and cultural interactions. In today's microprocessor-based digital technology world, Internet-related activities, when done properly, can lead to the creation of the so-called Infosphere, which is a system that includes multisourced knowledge integration, information accumulation, powerful visualization, virtual reality technologies, and retrieval and management procedures (Floridi 1999). A word of caution: The Internet is a valuable tool, but not a substitute for thinking. One should not use the Internet to conveniently *search* for a problem–solution (in the same way one searches for a French restaurant or a movie theater) instead of actually *thinking* about a solution. Yet one cannot underestimate the role of the Internet in debunking myths of the past. As has been observed, we were told that a million monkeys at a million keyboards could produce the "Complete Works of Shakespeare," but thanks to the Internet we now know that this is far from true.

At the same time, a distinction is made between the traditional versus the modern knowledge *society* viewpoints. The traditional view of a knowledge society includes a group of experts capable of providing specialist interpretations and aimed by technological gadgets. According to the traditional view (Popper 1968), *science* emerged as the formulation of statements of empirical facts about Nature, together with statements about relationships between facts, usually in the form of theories and laws (physical, biological, social, etc.). It is a major characteristic of science that both kinds of statements are subject to continuous testing by observation and experimentation. In modern times, another perspective has been proposed that considers the knowledge society as a society permeated with epistemic *cultures*, epitomized by science but structured in other areas of social life as well (Knorr 1999). In such a framework, a variety of important knowledge-related topics gradually arise, which range from the practical means of knowledge acquisition to the theoretical tools for understanding the nature of claims to knowledge (Giere 2006).

1.1.2 *Knowledge's Long Promenade: From Greece and China to Modern Times*

Our long promenade through the territories of knowledge (with its rewards and perils) has started. I suggest that the readers imagine themselves as the *Περιπατητικοί*,[3] the devoted students of knowledge and seekers of truth in ancient Athens. They were called *Περιπατητικοί* or *Peripatetics*, because they used to debate matters of human inquiry while taking long walks. *Περιπατητικοί* were among the first to promote an integrative approach to human inquiry and problem-solving.

1.1.2.1 Emerging Issues

Since the times when knowledge was first considered a subject of serious inquiry, a number of subtle issues emerged, such as: What humans can know and how? What is meant by knowledge? Can reliable or certain knowledge be available to humans? Is there a distinction between belief and knowledge? What is the role of logic in relating evidence with knowledge? How can a synthesis of knowledge sources solve real-world problems? What is the relation of knowledge and morality? Eventually, such questions became the subject of a principal branch of philosophy called *Epistemology*, which derives its name from the Greek words for knowledge (*επιστήμη*) and logos (*λόγος*). Below, I make an attempt to briefly yet critically review the thoughts of some of the brightest individuals who dealt with knowledge issues during the last 3,000 years.

1.1.2.2 The Ionian Thinkers and Parmenides' Poem

Sir Henry Maine maintained that, "Except the blind forces of Nature, nothing moves in this world which is not Greek in its origin." It then comes as no surprise that knowledge matters were debated among philosophers since the times of the birth of philosophy in ancient Greece. Those were the good old days! One cannot but full-heartedly agree with the historical perspective of Philip Brantingham (2007) that there are times when one yearns nostalgically for the good old days of the Pre-Socratic philosophers in ancient Greece, the days of Parmenides, Anaximander, Thales, Anaxagoras, Heraclitus, and Empedocles. These esteemed thinkers of the sixth and fifth century BC lived during a great and primordial era of western thought, a time when "wild and crazy" ideas floated around the Mediterranean, to be eventually passed down to the modern world. These men had an almost mystical relationship with Nature and continually ruminated on the origins of things. It was an amazing world that of the thinkers from Ionia. It was

[3] *Περιπατητικοί* (Walkers) were students of Aristotle's Lyceum in fourth century BC.

attractive in that it was a time of free thought, in which the ideas produced were based on empirical study as well as open speculation.[4]

Parmenides was a prominent member of this ancient school of thought. As far as we know, Parmenides' philosophical teachings are contained in a terse Poem (written in hexameters) already mentioned in the introduction to this chapter. In later antiquity, the Poem was sometimes called *Περί Φύσεως* (*On Nature*). It describes Parmenides' fascinating ascent to the home of a goddess who addresses him in the remainder of the Poem. He passes through the *Gate of Night and Day*, with the help of Sunmaidens (who persuade Dike the Avenger to unlock the gate) in order to meet the goddess who presents to him the two ways: the way of *Truth* and the deceptive way of *belief*. The readers may want to pause and imagine Parmenides' defining moment, when he passes from Night (the realms of error and uncertainty that characterized his former existence) into the Day (the realms of knowledge and truth now revealed to him). Remarkably, over the years there have been suggested different interpretations of what Parmenides' Poem is all about. Some studies have concluded that the Poem is about the universe, existence, and the oneness-of-it-all. According to Martin Heidegger (1998), for Parmenides the phenomenal world is a delusion, whereas what really matters is thought directed to the pure essence of *being*, seeking the highest level of knowledge (*νοειν́*) that will bring humans closer to the gods. Other interpretations, including Arnold Hermann's intriguing study of Parmenides, have argued that the Poem's main concern was about the integrity of human knowledge and communication, including our knowledge of the universe and the human existence, and the mode we choose to explain them (Hermann 2004). From this perspective, a central problem considered by Parmenides was how to ensure the *reliability* of discourse, a problem that will challenge some of the world's greatest minds for many centuries to come. Parmenides focused on sound reasoning, defending statements against self-contradiction, inconsistency, and the misleading plausibility of vagueness. According to Anthony A. Long, "What Parmenides says is a continuous provocation to our own *thinking about thinking*."

1.1.2.3 Xenophanes and the Reliability of Human Knowledge

Xenophanes was Parmenides' mentor and friend who exerted a significant influence on him. Xenophanes' basic teaching focused on whether certain or reliable knowledge can be available to humans. He is considered by many to be the father of *epistemological inquiry*. According to Xenophanes, only God knows the Truth, whereas the mortals, in time, by searching, could increasingly approximate the Truth. This way of thinking established for the first time an epistemological distinction between godly Truth and human belief. At the same time, it presented a devastating dilemma that has tortured philosophical thinking ever after, and would

[4] I hope the readers tolerate my recourse to romantic nostalgia throughout the book.

condemn all knowledge to the twilight of relativity. According to some scholars, it was Xenophanes' original thinking that moved Parmenides to look into the matter of knowledge reliability in considerable depth. It also formed the basis of the *scientific process*, which is why it is considered as a tremendously significant achievement in science and epistemology (Popper 1998). Xenophanes argued that certain knowledge was not possible, because even if a human agent hits upon the truth by chance, there is no way of knowing for sure that things are as the agent thinks they are. However, this situation by no means makes human inquiry pointless, since by exposing errors in their reasoning mode the agents can find out what certainly *is not* the case, even if they cannot say with certainty what *is* the case. The above conceptual framework has found its modern counterpart in the *falsification* principle of Karl Popper. Falsifiability (also known as refutability or testability) is the principle that although an assertion (hypothesis or theory) cannot be proven correct with certainty, it can, nevertheless, be shown false by an observation or an experiment. In particular, an assertion is scientific only if it is falsifiable (i.e., an observation or experiment can be described that can potentially falsify the assertion).

Parmenides made an original and serious attempt to respond to the doubts expressed by Xenophanes concerning the *inherent relativity* of human knowledge. From this perspective, Parmenides' story is closely linked to the eternal search of humanity for understanding and truth. His main proposal was that more than evidence it is critical reasoning that can contribute to the generation of reliable knowledge. Parmenides discussed a number of methods based on argumentative devices, which even today constitute a powerful tool in the hands of an expert. In particular, one of Parmenides' methods toward reliable knowledge is "contradiction," which he views as a negative approach with a positive result: By expositing or provoking contradictions concerning a situation, the only possibility left must be true. In such a framework, one of the ground-breaking principles proposed by Parmenides was that, "What can be refuted must be refuted, what cannot be refuted must be accepted as true." Interestingly, this statement is echoed in a nineteenth century quote by the fictional British detective Sherlock Holmes: "When you have eliminated the impossible, whatever remains, however improbable, must be the truth."

1.1.2.4 Skeptics from Greece and China Enter the Scene

As we saw above, Epistemology was born as a branch of philosophy that deals with the nature of knowledge. In the process, a series of questions continued to arise concerning knowledge reliability. In ancient Greece, *skeptics* questioned whether appearances are a reliable guide to reality. Using the paradox (i.e., a statement that entails its negation) as their principal weapon, they argued that human claims to knowledge are rarely, if ever, justified. Not surprisingly, Plato was severely disturbed by the teachings of ancient skeptics. However, many scholars argue that skeptics prevented dogmatism in human inquiry, and reinforced the view that the inquiry must go through a *what-if* stage before it is able to obtain knowledge. As we will see in Section 5.3.1, this stage is at the center of the conceptual framework of stochastic reasoning.

But skepticism was not a movement that flourished in ancient Greece alone. While the above developments were taking place in the western world, in ancient China the *Taoist* (also called *Daoist*) philosophy was highly skeptical of any absolute claim to knowledge. This kind of skepticism is clearly demonstrated in the famous quote by Lao Tzu: “One who knows does not speak. One who speaks does not know.” The readers may find it interesting to compare this statement with Ludwig Wittgenstein’s modern quote: “What can be said at all can be said clearly, and what we cannot talk about we must pass over in silence.” Lao Tzu was one of the fathers of Taoism who, according to Chinese tradition, lived in the sixth century BC.[5]

The readers may find it interesting that some modern skeptics merely question the part of the real-world that cannot be observed, thus leading to certain long-standing distinctions, such as rationalists versus empiricists. *Rationalists* (like René Descartes) believed that pure reason can yield knowledge by itself (which indicates Parmenides’ influence on Descartes’ thought), whereas *empiricists* (like David Hume) claimed that sense-experience is always needed for knowledge generation (which is a view with an Aristotelian influence). I plan to revisit this highly consequential distinction in other parts of the book. At the moment, it suffices to say that recent developments in *empirical skepticism* suggest approaching one’s own work in a reflective and inquiring way that necessarily embraces in situ uncertainty, especially in the case of highly improbable phenomena encountered in real-world problem-solving (Coleman 2001; Taleb 2008a).

1.1.2.5 Seeking a Definition of Knowledge Through the Ages

In light of the above considerations, one may wonder what exactly is meant by “knowledge” and “understanding.” As is the case with all important subjects in the history of human thought, from ancient to modern times, the definition of knowledge has been an open and continuing debate. Let us glean the perspectives on the matter of some of the world’s most eminent thinkers. Needless to say that the list is representative although by no means exhaustive.

Plato provided the classic definition of knowledge as the “justified true belief” (Plato 1921). More specifically, in order to know something, the agent must believe it, it must be true, and the agent must have a justification for believing it. This definition, although imperfect, has been used for more than 2,000 years, which offers a strong testimony of the great man’s influence (Cornford 1935). In Bernard Russell’s account (Russell 1945), “Plato derived the negative doctrine that there is nothing permanent in the sensible world. This combined with the doctrine of Parmenides, led to the conclusion that knowledge is not to be derived from the senses, but is only to be achieved by the intellect.” This was the view held by many

[5] Although many historians claim that he actually lived in the fourth century BC.

twentieth century Platonists, including the eminent logician Kurt Gödel. Also interesting is Aristotle's view about knowledge (Aristotle 2004: 29):

> We consider that we have unqualified knowledge of everything (as contrasted with the accidental knowledge of the sophists) when we believe that we know (*i*) that the cause from which the fact results is the cause of the fact, and (*ii*) that the fact cannot be otherwise.

In the fourth century BC, Isocrates was convinced that knowledge is tentative, i.e. humans cannot know anything for sure – only useful opinions are possible (Eucken 1983). This is a viewpoint that two millennia later was endorsed by several modern thinkers, like the great mathematician and computer scientist John von Neumann, who believed that science is not after absolute knowledge but rather seeks to construct models that are justified solely on the basis that they are expected to work. It is worth-noticing that ancient Egyptians were not interested about the nature of knowledge in itself, although they were deeply concerned with questions of proper conduct and justice (Hornung, 1999). Their views emphasized pragmatism (finding a practical solution to a specific problem, without generalizing to abstract laws), flexibility (offering several possible explanations), and attention to emotion (believing that the heart was the organ of thought, and recognizing the lure of emotion).

About the same time on the other side of the Earth, the Chinese philosopher Confucius believed that there was no inborn knowledge.[6] To know Nature and the *way* of Nature, one must observe and process one's observations according to the principle of one's own mind (Bahm 1992). In the Confucian tradition of ancient Chinese philosophy, the focus was on practicality. There was no thought of knowing that did not entail some consequence for action. Accordingly, a noteworthy distinction between the ancient Chinese and Greek cultures regarding the concept of knowledge is that (Harbsmeier 1993: 14, 22), "There is little room in traditional Chinese culture for knowledge for its own sake. There was little enthusiasm for 'academic knowledge' as cultivated by philosophers such as Plato and Aristotle, who continued the heritage of Socrates. For the ancient Chinese it was action that was primary, personal action and political action. . .When ancient Confucian and Legalist texts address the problem of *zhi* (knowledgeable, intellectual excellence), they do not address a problem of epistemology at all. Often they address a problem of public administration." In his teaching, Chuang Tzu (or Zhuangzi) emphasized tacit knowledge and intuition (knowledge that is natural and sometimes implicit) rather than formal and externally derived knowledge. The former kind of knowledge leads to new ways of viewing the real-world that can deepen and broaden perspectives (Chang 1975). As was usual practice in those days, Chuang Tzu summarized the relationship of tacit to external knowledge in a famous poem:

> The fishing net serves to catch the fish; let us take the fish and forget about the net. The snare serves to catch the rabbit; let us take the rabbit and forget about the snare. Words serve to convey ideas; let us take the ideas and forget the words.

[6] In this respect, early Chinese philosophy shares much in common with seventeenth century British empiricists.

During the period between fifth and eleventh centuries AD Arabs expanded the domain of knowledge by discovering algebra, and introducing major developments in philosophy, astronomy, and architecture. They translated ancient Greek texts into Arabic (a large translation bureau was established in Baghdad's *Bayt al-Hikma*). This knowledge (*Studia Arabum*) was brought back to Europe by travelers like the English scholar Adelard of Bath. In the thirteenth century, St. Thomas Aquinas suggested that knowledge is the understanding of what agents perceive. When agents are born, they have the potential to know and learn, but they do not know anything yet. With time and effort, experience and reasoning improve their potential for understanding (Copleston 1955). In the fourteenth century Byzantium, George Gemistos Plethon deified knowledge by including a prayer to the gods of learning in his seminal *Book of Laws* (Herrin 2008: 295):

> Come to us, O gods of learning, whoever and however many ye be; ye who are guardians of scientific knowledge and true belief.

Descartes (1641) believed that knowledge is obtained by logical deduction, i.e. a mental process by which agents understand all necessary inference from other facts that are known with certainty. In the eighteenth century, Immanuel Kant (1902) identified a twofold relation of knowledge: A relation to the object (attribute, phenomenon, or system) and a relation to the subject (agent's consciousness, the way one obtains knowledge about the object). For Georg Wilhelm Friedrich Hegel, knowledge is a dynamic cultural and historical process he called *dialectic*, during which ideas grow and move toward an improved grasp of reality (Beiser 2005). In this sense, understanding is a relationship between the agent and what appears to be the surrounding environment. Knowledge is always contextually dependent, and often the result of a series of conflicting positions.

During the twentieth century, several important developments took place. In the 1920s, the eminent physicist Werner Heisenberg discovered some unexpected yet fundamental difficulties in knowledge acquisition (Heisenberg 1958). According to his uncertainty principle, one could not always know what one needs to know, and the knowledge acquisition process could affect the knowledge obtained (the act of observing changes the entity observed). For Ludwig Wittgenstein (1999), to understand the word "knowledge," one needs to look at ordinary (nonphilosophical) language to see how the word is used. In ordinary language, the word has ready context-dependent criteria for being used, whereas in a philosophical context it obtains a stronger meaning. Hence, one should take natural language as its starting point, and proceed from there. Karl Popper (1934) considered "knowledge" in the objective or impersonal sense (i.e., knowledge contained in books, stored in libraries, or taught in universities). He proposed that the making of highly falsifiable statements was more relevant to the advancement of knowledge than seeking truth merely by empirical proof. Willard Van Orman Quine (1970, 1990) believed that knowledge is inevitably holistic. For him, knowledge is a "matrix," a "web," or an integrated body of beliefs that can be changed by experience. This is valid even for one's "beliefs" in mathematics.

Many other eminent philosophers and scientists have struggled with the subjects of "knowledge" and "understanding," and have provided valuable suggestions and insights. According to some authors, knowledge has been basically reinvented six times in western history, in the form of the "Library," the "Monastery," the "University," the "Republic of Letters," the "Disciplines," and the "Laboratory" (McNeely and Wolverton 2008). Modern cognitive science maintains that knowledge involves complex processes of perception, learning, communication, association, and reasoning. From a biological viewpoint, some authors argue that knowledge resides in the DNA of the genetic code (Shimanovsky et al. 2003). Moreover, in an evolutionary computational sense, "understanding" may be defined as a very compressed representation of the world (Baum 2004). Modern sciences increasingly offer answers to knowledge-related questions that traditionally belonged to the domain of the humanities (why humans believe in God, hate their enemies, love their parents, and the like). Due to space limitations, an exhaustive presentation of the subject is not possible in this book, in which case the readers are referred to the rich literature available.

1.1.3 Knowledge Classifications

Knowledge is an extremely important and vast topic of human inquiry, which explains why one finds several different *classifications* of knowledge in the literature. Some of these classifications are touched upon in the following lines.

1.1.3.1 Standard Classifications

Standard knowledge classifications include: (*a*) *Acquaintance* knowledge, *ability* knowledge, and *propositional* knowledge (mainly the focus of science).[7] (*b*) *Prior* knowledge (its justification does not rely upon empirical evidence) and *posterior* knowledge (its justification relies upon empirical evidence).[8] (*c*) *Analytic* knowledge (true by virtue of the meaning of the words) and *synthetic* knowledge (true by virtue of its meaning and certain facts about the world).[9] (*d*) The analytic–synthetic distinction and the prior–posterior classifications can be combined to yield four types of knowledge: analytic a priori, synthetic a priori, analytic a posteriori, and synthetic a posteriori.

Some knowledge types take the form of presumptions that belong to the system of concepts, which form the frame in which agents paint pictures of the real-world (the "frame-picture" idea was originally suggested by Kant and Wittgenstein). In the IPS

[7] Examples of the three knowledge types in classification *a* are, respectively, "Maria knows the U.S. President," "John is a good mathematician," and "Aspasia knows that Spartans are Greeks."

[8] Examples of the two knowledge types in classification *b* are, respectively, "all bachelors are unmarried," and "this car is red."

[9] Examples of the two knowledge types in classification *c* are, respectively, "all triangles have three sides," and "there are no elephants in Greece."

setting, the term "synthetic a priori" may denote working presumptions of perception, thought, and action that are not derived from the agent's experience but play an important role in the mind's synthesis of empirical data and thought processes.

1.1.3.2 Knowledge Versus Belief

Since Plato's time, it was already intuitively clear that there exists a substantive difference between *belief* and knowledge: Whatever people happen to believe as true does not necessarily qualify as knowledge (e.g., many people believe that Elvis is alive, but this can hardly be regarded as knowledge). If it cannot be rigorously justified (supported by evidence and/or sound reasoning), even if a belief is true, it does not qualify as knowledge.

There exist many approaches that claim to provide tools by means of which a belief can be appraised whether it counts as knowledge or not. Among these approaches, one finds *Reliabilism*: A mechanism is usually considered reliable if there can be established a causal connection between what the belief is about and the belief itself; if the mechanism by which a belief is formed is reliable, then the belief is justified (Goldman 1967). A human agent's belief, e.g. that there is a book on the table, is produced by vision, which is viewed as a fairly reliable mechanism, and, according to reliabilism, the belief is justified. The interested reader is referred to the relevant literature for a critical discussion of the *pros* and *cons* of reliabilism.

1.1.3.3 Reality-Based Knowledge Classification

Some scholars distinguish between knowledge that refers to *material* reality and knowledge that refers to *immaterial* reality. The former is associated with physical attributes (e.g., weight and temperature) and is constrained by the laws of Nature, whereas the latter is associated with nonphysical attributes (e.g., human character and compassion) and is not constrained by natural laws. In such a classification milieu, a number of questions emerge: Are the two kinds of reality separate and distinct, or is one reality a consequence of the other? If the two realities are separate, how do they interact? How does material reality give rise to conscious thoughts?

These questions are closely linked to major issues of human understanding, from very theoretical (e.g., the "brain–mind" debate in sciences) to very practical (e.g., the 2008 worldwide financial downfall was primarily the result of *corporatism*'s[10] self-serving rejection of the reality of sound economics in favor of the virtual reality of greedy markets). Before leaving this thought-provoking section, I should mention that

[10] One should distinguish between corporatism and capitalism. Corporatism has been termed "The greediest form of capitalism" (Grayling, 2010: 393). In capitalism the free markets need a moral foundation in order to work; and when a company fails, it is not bailed out using taxpayer money. Corporatism generally refers to the control of a state, an institute, or an organization by large financial interest groups; access to federal lending, deposit insurance, government guarantee for corporations "too big to fail;" and a voracious, interventionist bureaucracy.

issues such as the above are not solely philosophical, but they lie at the center of real-world IPS, which is why I invite the readers to revisit them together in various parts of the book, and in different contexts. Within the same framework of thought, IPS should take advantage of philosophy's high practical value to bring the relevant presumptions to critical scrutiny, clarify ideas, and remove misunderstandings.

1.2 Matters of Scientific Knowledge

Scientific knowledge is an important branch of knowledge that is acquired and processed by agents using the thinking modes and methods of sciences. Physical knowledge, e.g., is knowledge acquired by the methods of physical science, whereas social knowledge is that which comes to humans by the methods of social science. Scientific knowledge has been characterized as general, empirical, quantifiable, explanatory, and with predictive power. It usually refers to a natural system (physical, biological, social, or cultural) characterized by certain *attributes* with values distributed in the space–time domain. Examples of real-world attributes include temperature, weight, pollutant concentrations, soil properties, water resource parameters, land use variables, disease incidence, mortality, happiness index, regional poverty level, and commodity prices.

1.2.1 The Agent–Problem Dialectic

Generally, scientific IPS seeks answers to substantive questions about natural systems and attributes on the basis of empirical evidence and testable scientific theories. As such, IPS is often an open rather than a closed system that includes several scientific disciplines under conditions of multisourced uncertainty. IPS's *modus operandi* involves certain basic stages, as follows. Via some *inferential* process (characterized by its thinking mode and underlying worldview), an investigator seeks the acquisition and description of the *knowledge bases* (theoretical and empirical, yet usually incomplete) that are relevant to the problem (Section 3.6). This description includes modeling knowledge in a certain manner (formal, quantitative, etc.) to render it implementable and communicable. The result of the above process is an adequate *problem representation*. Solutions to the problem are subsequently obtained by synthesizing different (in kind and substance) pieces of knowledge based on the *dialectic* between the investigator (consciousness) and the problem (empirical observations). The terms "inferential" and "dialectic" deserve some further elaboration.

Although not always adequately appreciated, the inferential process must be able to discriminate between knowledge that is significant versus knowledge that is trivial; knowledge that has energy versus knowledge that is merely a static piece of data; knowledge that leads to a solution with powerful consequences versus knowledge that yields banal and uninspiring solutions. Every time-period generates large amounts of data that, while at the time were considered indispensable, most of them were later proven to be tautological, useless, or even false. More often than not, while convenient to a group of scientists, most of the data contribute nothing to the understanding of the problem and its solution. Furthermore, one must investigate carefully the consistency of the multidisciplinary knowledge bases considered in IPS. This is an important twofold task that relies on the justified choice of the knowledge elements to abandon in order to restore *consistency*, and the choice of the judicious approach that can incorporate the remaining elements into the IPS framework. Usually, there exists more than one combination of knowledge elements that could be abandoned in order to avert inconsistency, and a variety of distinct ways to process the remaining elements into the IPS framework. As a result, one reaches the bold conclusion that the framework should be based on a firm dialectical structure, rather than a set of content-free techniques that exist independent of the investigator. Some key elements of the "agent-problem" dialectic may be illustrated with a simple example, as follows. There are two distinct knowledge aspects in considering a physical object such as a chair: (*a*) One aspect is associated with *agent-independent* facts like the material the chair is made of, the physical laws obeyed by the chair,[11] and the fact that the chair will still be there if the agent leaves the room. (*b*) Another aspect is *agent-dependent* and consists of the agent's private experience, also known as "consciousness," of the specific chair, including the unique chair-feeling and chair-watching experience of an agent that no one else can know what it is like.[12] Two critical issues to be contemplated in any meaningful real-world study are how aspects *a* and *b* are related to each other, and how they affect the solution of the problem. These issues need to be considered, studied, and answered in an adequate manner, which explains why the issues arise in various parts of this book, in a direct or indirect manner, where they are appraised within different IPS contexts and viewed from different perspectives.

1.2.2 Napoleon's General

Esse est percipi said George Berkeley. If being is perception, there is no doubt that the way one perceives a real-world problem exerts a critical influence on its solution (Chapter 3). Inadequate problem perception can turn out to be part of the problem itself, often mystifying it instead of enabling one to solve it. In other words, there are not only wrong answers and solutions, but there are also wrong questions and problem perceptions. An IPS approach should involve a balanced combination of three critical ingredients that form a sort of a *trinity*: (*a*) *Scholarship*, which implies a deep understanding of the relevant fields of knowledge to avoid focusing on issues that are irrelevant to the problem of interest, using outdated conceptual frameworks and tools, and developing wide-ranging theories that are neither original nor flawless. (*b*) *Methodology*, which is concerned about how and when to use various

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[11] If, e.g., one raises the chair and let it go, the chair will fall downwards according to the laws of gravity.

[12] For example, the feeling of the chair's texture and smell, the experience of the chair's color and shape are unsharable. See, also, the concept of "qualia" in Section 3.2.3.

methods to develop knowledge and solve problems, and about what each method really means (underlying conceptions, presumptions, normative rules, and reasoning modes). (*c*) *Insight*, i.e. an ability to see what really is at stake. Unless one can spot what really matters, scholarship simply buries one in the thought of others; and to avoid an aimless inquiry, an agent should use an insightful methodology that is at the service of what lies at the crux of the matter.

The plausible question emerges whether the above trinity (scholarship, insight, and methodology) is sufficient for the solution of every in situ problem conceivable? Apparently not – often in life there is more to be desired. Worth mentioning is the following historical anecdote. When he was informed about a newly appointed general and his impeccable qualifications, Napoleon famously asked: "Has he luck?" Like many leaders in politics, warfare, and business, Napoleon was well aware of the role "lady luck" plays in life. History abounds with examples in which the crucial factor that decided the fate of a situation (the career of an individual, the destiny of a nation, the outcome of a crucial battle, the result of a path-breaking experiment) was largely a matter of chance. Adam Smith believed that the reason free markets work is because they allow people to be lucky (Taleb 2008a). Sergey Brin (co-founder of *Google*) went even further: "The number one factor that contributed to our success is luck."[13] For Stephen Jay Gould, chance played a significant role in evolution to the point that, "the modern order is largely a product of contingency" (Gould 1989). Every scientific investigator knows that, in addition to the trinity above, in many cases an extremely important fourth factor of successful problem-solving is chance or luck. Famous is the accidental discovery of penicillin by the Scottish biologist Alexander Flemming. Chance events and accidents can lead to breakthroughs, if someone knows how to interpret them. As one of the founders of microbiology Louis Pasteur once put it, "Chance favors the prepared mind" (Roberts and Roberts 1994). Hence, chance is as scientific and fixed as gravity, whereas many people view "luck" as just a matter of rolling the die of life. The gist of the whole matter is concentrated in the realization that, if the three distinct critical ingredients of scientific inquiry above constitute a trinity, then the presence of chance reminds us that there is one crucial element that links these ingredients, a *unity* so to speak: The investigator's self-awareness concerning *how much one does not know*. The same unity brings to the fore the subjects of knowledge reliability and uncertainty assessment.

1.2.3 The Emergence of Stochastic Reasoning[14]

In human history, empirical reasoning precedes formal logic. *Scientific reasoning* is the capacity to argue and connect items of knowledge about a phenomenon, and

[13] Along similar lines is the old Greek folk proverb: "A man may possess a mountain of skill and talent, but if he lacks a small pebble of luck, he rarely accomplishes much in life."

[14] "Stochastic" is an ancient Greek word that refers to deep or intense thinking; it does not merely mean "random," or "science of prediction" as is sometimes assumed (e.g., Collani 2008: 202).

draw from them new conclusions, so extending human understanding and solving real-world problems. Sound reasoning is the *sine qua non* of IPS, but as long as knowledge is a fluid thing, even a solution based on sound reasoning cannot be an absolute truth, but a "truth in the making" at best. Regarding mathematics, formal *logic* is a very useful tool for generating knowledge starting from true premises. On the other hand, *scientific epistemology* has been developed as that branch of epistemology that is concerned with matters of scientific knowledge. It is mentioned in passing that, traditionally a distinction is made between science (treating the content of knowledge) and epistemology (focusing on the nature of knowledge). Some modern views, however, argue that epistemology should be included in sciences.

1.2.3.1 Scientific Reasoning and Formal Logic

With regard to the possible link between scientific reasoning and mathematical logic, Sir Arthur S. Eddington suggested that, "Theoretical scientists, through the inescapable demands of their own subjects, have been forced to become epistemologists just as pure mathematician have been forced to become logicians." Although this is not necessarily implied by Eddington's statement above, certain scientists have suggested that in order to be meaningful, a scientific statement must be a formally logical and verifiable statement. Nevertheless, it should be clear that formal logic is not a panacea. Instead, when it comes to its application in real-world situations, the determinism of formal logic has its own limitations. Formal logic guarantees the validity of the derived outcome assuming that the initial premises are true, but it cannot prove that the premises themselves are valid. Human insight and intuition are richer than deterministic logic whose norms are content-free. These norms neglect the fact that agents operate in the real-world that is an open system (characterized by sizable uncertainty and a variety of auxiliary conditions) rather than the idealistic closed system of deterministic mathematics.[15] Investigators should always keep in mind these limitations when viewing mathematical logic as an essential IPS ingredient. Nothing should be used uncritically. Neglecting the contentual aspects of a logical process, and focusing instead on its formal aspects can legitimize almost any kind of action. As we saw in Section 1.1.1, the officer on duty in the destruction of the library of Alexandria justified his barbaric actions in terms of a logical process based on the initial premise that the truthfulness of the Koran is unquestionable. The rest is history.

The convenience of the "black-box" culture is a thinker's worst enemy. This is valid even for highly influential intellectual developments. Gottfried Wilhelm

[15] In real life the right decision cannot be always based on pure logic (e.g., not even a pair of shoes one buys based only on purely logical criteria, say, size and price). Life does not progress with dry data alone, with the 0-1 (yes-no) of computers; there are an infinite numbers of values in between, which give depth and quality to human knowledge.

Leibniz's *reductio ad absurdum* method[16] assumes that every statement is either true or false, but offers no support for this assumption. As it turns out, the in situ validity of the assumption may be questionable, since an agent cannot know for sure that a statement is true or false. In fact, it is the in situ circumstances described above that make it necessary to replace deterministic statements with indeterministic ones, and in the process change the investigator's mode of thinking.

1.2.3.2 Changing the Thinking Mode

It was soon realized that classical logic was ill equipped to handle notions like "possible" or "probable," and to make predictions under realistic conditions of uncertainty. Willard Van Orman Quine (1970) believed that science is "undetermined" in the sense that the available evidence is incomplete and uncertain, whereas underlying any theory or model there is a web of interrelated hidden presumptions and questionable premises that make it impossible to derive the truth or falseness of relevant statements by means of classical logic. Therefore, in many in situ cases, it makes more sense to talk about *probable knowledge* rather than about certain knowledge, the latter being merely a special case of the former under limited (and often unrealistic) conditions. Admittedly, an investigator needs to address a number of critical issues about probable knowledge. One such issue has to do with the appropriate interpretation of abstract statements like, "the probability to rain tomorrow." Should this probability be seen as an integral part of the investigator's description of the world or it merely reflects incomplete knowledge about the exact state of the world? Should the probability be understood in terms of frequencies or derived from statements relevant to the description of the world? I will revisit probability interpretation matters in Chapter 4.

Leibniz was probably the first to emphasize in the early 1700s the need for a kind of logic that would treat degrees of probability, including a means for estimating likelihoods and a way of proof leading to probability rather than certainty (Hailperin 1984: 198). In modern times, both deductive and inductive logic systems with a strong probabilistic component have been suggested for scientific reasoning purposes (Carnap 1950; Cox 1961; Kyburg 1970; Adams 1975; Nilsson 1986; Jaynes 2003). One of the best known such systems is *logical positivism*. In its rather extreme case, a solution approach is merely an instrument. Many scientists have been highly critical of positivism as a system that confuses the meaning of a concept with the way in which numerical values of the entities associated with the concept are determined (Cook 2002). Certain studies assign probability values to sentences, including the work of Haim Gaifman (1964) that proposed a generalization of the semantic notion of a model for a first-order language in which probability values replace truth-values. The analysis was extended to infinitary languages, and

[16] Reduction to the absurd is a form of reasoning in which a claim or a statement is disproven by following its implications to a logical but absurd consequence.

a probability logic was developed accordingly (Scott and Krauss 1966). On the other hand, Theodore Hailperin (1984) developed a probability logic at the propositional level. Mathematical theories of evidence based on belief functions and plausible reasoning have been also proposed (Shafer 1976). In a similar milieu, the so-called canon of plausible inference is an attempt to account for a set of rationality and morality demands in order to build plausible logic languages with observations and derive probability calculation and assignment rules (Solana-Ortega and Solana 2005). Difficulties with probabilistic logics are linked to their highly abstract nature and the involvement of computationally complex probabilistic components and logical statements.

1.2.3.3 The Prime Role of Natural Laws

This book considers *stochastic reasoning* as a crucial component of the contemplated real-world IPS approach. Let me begin by giving a brief introduction to the main elements of stochastic reasoning. Each of these elements will be presented in greater detail in the following chapters. Stochastic reasoning is the kind of reasoning in which chance and necessity constitute an integrated whole; the structure from which a formalism is abstracted is often richer than the formalism itself; a context- and content-dependent mathematical representation of the problem–solution is sought that may require the development of a suitable metalanguage; and core and site-specific knowledge bases are blended in terms of a solution process that emphasizes meaning and has well-defined goals. The last feature is most important for stochastic reasoning: an agent's epistemic situation usually includes a knowledge base (natural laws, scientific theories, and empirical data), which should be incorporated into the agent's thinking mode in a coherent and consistent manner. For the readers' benefit, a representative list of natural laws from different disciplines is given in Table 1.1. The notion of a "law" may differ between disciplines. One must distinguish, e.g., between a science law (explanatory, predictive etc.) and a social law (prescriptive, normative etc.). The laws often connect observational or detectable terms with theoretical terms. This includes ab initio (i.e., derived from first principles) and phenomenological laws describing the evolution of the corresponding attributes across space–time (e.g., Black and Scholes 1973; Bower and Hilgard 1981; Bothamley 2002; Lide 2009). Obviously, not all laws have the same level of fundamentality. The laws of one discipline (say, physics) are more fundamental than another's (say, economics). Within the same discipline itself, some laws are more fundamental than others (the physical laws of quantum mechanics are more fundamental than those of classical mechanics). There are phenomenological laws (describing a body of knowledge that relates empirical observations of phenomena to each other), and laws that specify the basic underlying mechanisms of Nature (which may be not directly observable). These and similar classifications imply that there is a certain epistemic overlapping between the terms "natural law" and "scientific law" (Hanzel 1999).

Mathematical descriptions of many natural systems lead to laws expressed in terms of algebraic, differential, or integral equations, and combinations thereof.

Table 1.1 Examples of natural laws

Physics	Abney, Archimedes, Bernoulli–Euler, Biot, Boltzmann, Bose–Einstein, Clausius, Coulomb, Curie, Euler, Faraday, Fick, Fresnel–Arago, Heisenberg, Hooke, Joule, Kirchhoff, Lambert, Maxwell, Newton, Ohm, Planck, Rayleigh, Schrodinger, Snell, Steinmetz, Wien
Chemistry	Avogadro, Beer–Lambert, Bouguer–Lambert, Boyle, Coppet, Dalton, Einstein–Stark, Fajans–Soddy, Gay–Lussac, Humboldt, Maxwell–Boltzmann, Nernst, Ostwald, Proust, Raoult, Retger, Sommerfeld, Wenzel, Wullner
Earth and Atmospheric Sciences	Archie, Bernoulli, Braggs, Buys–Ballot, Darcy, Dittus–Boelter, Drude, Egnell, Glen, Hack, Hale, Hazen, Hilt, Hopkins, Jordan, King, Kramer, MacArthur–Wilson, Richard's, Steno, Stokes, Wake, Walther, Werner, Young–Laplace
Life Sciences	Behring, Bowditch, Courvoisier, Dastre–Morat, Dollo, Du Bois, Elliott, Edinger, Emmert, Farr, Gloger's, Gogli, Gompertz, Haeckel, Hardy–Weinberg, Liebig, Mendel, Reed–Frost, Wallace, van Valen, von Baer, Yoda, Zeune
Psychology	Bell-Magendie, Charpentier, Ebbinghaus, Fechner, Fitt, Fullerton–Cattell, Hick–Hyman, Horner, Jackson, Jost, Korte, Merkel, Piper, Ricco, Talbot-Plateau, Vierdot, Weber
Economics	Engel, Goodhart, Gresham, Hotelling, Okun, Pareto, Say, Verdoorn, Wagner, Wald

In the stochastic reasoning milieu, these equations are formulated so that for any given boundary and initial conditions, a probability distribution over all possible space–time points of the system domain can be specified. In this case, one talks about *stochastic laws* that describe the evolution of the attribute probability functions or some statistical features of the attribute. In a sense, the stochastic laws represent physical propensities of the in situ system to evolve in a certain way under conditions of uncertainty. These matters will be presented in greater detail in Sections 5.5.3 and 5.6.2.

1.2.3.4 The Metalanguage

A few simple examples would illustrate some basic ideas of stochastic reasoning. Consider an entity *A* (event, proposition, attribute, phenomenon, or state). Stochastic reasoning switches focus from the statement "*A occurs*" to the statement "*Agent's assertion that A occurs*."[17] The former statement refers *to A* itself and belongs to language, whereas the latter statement refers to the agent's assertion *about A* that belongs to *metalanguage*. Metalanguage assertions are not definite but rather conditioned on the available (often incomplete) knowledge. This means that to each assertion the agent's stochastic reasoning assigns the probability[18]

[17] Or, the assertion of a group of agents.

[18] The η is a real number between 0 and 1.

$$P_{KB}[A] = Prob[Agent's\ assertion\ that\ A\ occurs\ in\ light\ of\ KB] = \eta, \tag{1.1}$$

where KB denotes the knowledge base associated with the agent's epistemic situation that substantiates the probability the agent assigns to the assertion about A. Clearly, $P_{KB}[KB] = 1$, regardless of whether KB is certain or uncertain knowledge. The epistemic situation represents the cognitive state of the agent, in which the epistemic situation is not seen as a purely psychological state, but rather as a product of the rational representation of the KB in the context of the agent's thinking mode. Otherwise said, the term "Agent's assertion" in Eq. (1.1) is not meant in the purely personalistic sense, but it is based on the substantive consideration of the scientific theories, physical laws, empirical evidence, etc. that constitute the KB. Therefore, probability (1.1) is relativized to the KB, which is then combined with logical reasoning in order to calculate the η value. In this sense, the term "epistemic" has an objective flavor: any rational agent in the same epistemic situation should calculate the same η value. This all makes sense, at the moment, but there is more to be said. Often, the agent's reasoning includes certain mental functions (e.g., teleology of reason, intentionality, or adaptation; Chapter 3), in which case both the KB and the operationally formulated mental functions could be involved in the calculation of the η value. For illustration purposes, let the entity A represent the attribute $X_{\boldsymbol{p}}$ that varies in a physical space–time continuum $\boldsymbol{p} = (\boldsymbol{s}, t)$.[19] The KB is: $X_{\boldsymbol{p}}$ *varies according to the natural law* $M_X[X_{\boldsymbol{p}}] = 0$ *with BIC*,[20] $X_{\boldsymbol{0}} = \chi_{\boldsymbol{0}}$. Then,

$$P_{KB}[X_{\boldsymbol{p}} \leqslant \chi_{\boldsymbol{p}}] = Prob[Agent's\ assertion\ that\ X_{\boldsymbol{p}} \leqslant \chi_{\boldsymbol{p}}\ in\ light\ of\ M_X[X_{\boldsymbol{p}}] = 0,\ X_{\boldsymbol{0}} = \chi_{\boldsymbol{0}}] = \eta. \tag{1.2}$$

Otherwise said, the agent's assertion and the assigned probability in Eq. (1.2) are justified by appeal to KB. In quantitative terms, the calculation of η in Eq. (1.2) may be also expressed by

$$\left.\begin{array}{r} M_X[X_{\boldsymbol{p}}] = 0 \\ X_{\boldsymbol{0}} = \chi_{\boldsymbol{0}} \end{array}\right\} \Rightarrow P_{KB}[X_{\boldsymbol{p}} \leqslant \chi_{\boldsymbol{p}}] = \eta, \tag{1.3}$$

which means that the calculation of the probability value primarily involves knowledge of the natural law. In several real-world cases, one may seek a problem-solution that maximizes a certain goal or characterizes an intention (monetary gains, happiness, knowledge etc.; Rosen, 2003). If, e.g., in addition to the KB, the agent's epistemic situation includes the intentionality (mental) function of maximizing the information state (InfoState), Eq. (1.3) may be replaced by

[19] The $\boldsymbol{s}$ denotes the spatial location vector and t denotes time (Chapter 4).

[20] Boundary and initial conditions.

$$\left.\begin{array}{l}\max[InfoState] \\ s.t.\ \ M_X[X_{\boldsymbol{p}}]=0 \\ X_{\mathbf{0}}=\chi_{\mathbf{0}}\end{array}\right\} \Rightarrow P_{KB}[X_{\boldsymbol{p}} \leqslant \chi_{\boldsymbol{p}}]=\eta. \tag{1.4}$$

Equation (1.4) may be seen as a rational formulation of the mental state of intentionality based on the agent's epistemic situation. A more detailed analysis is found in Chapters 5–7.

One more thing to be noticed is that underlying the symbolic representation (1.1) is the viewpoint that in the real-world the entity A does not always have to make sense strictly within the boundaries of a specific world perspective (regardless of how deeply entrenched into an agent's consciousness this perspective currently is) in order to be the way it is. Rather, an entity A that seems not to make sense or is unknowable within the old KB, may turn out to make perfect sense and be knowable within the new KB. Typical, in this respect, is the case of quantum physics entities (phenomena, statements, etc.) that do not conform to the verbal-semantic definitions of the deterministic (mechanistic) worldview but, nevertheless, are perfectly reasonable in the context of the indeterministic worldview. The above considerations demonstrate the importance of metalanguage and the associated epistemology in scientific IPS. To take an extreme case, if instead of a principled and rigorous science-based metalanguage, an agent employs the flawed metalanguage of the shadow epistemology (Section 1.4), the assertions about an entity A and the associated probabilities are highly questionable. And so are the derived solutions of the real-world problem.

The analysis above can be extended to several entities. For example, consider two entities A and B. In formal probability analysis (Chapter 4), the symbol $P[A \wedge B]$ refers to the probability that "both A and B are true," whereas in stochastic reasoning, the $P_{KB}[A \wedge B]$ denotes the probability of the "Agent's assertion that A is true and agent's assertion that B is true in light of the agent's epistemic situation." Due attention should be paid to the interpretation of other terms used in a stochastic reasoning setting, like "implication," "causation," and "synthesis." In fact, probable statements about Nature often assume the symbolic representation

$$P_{KB'}[B]=P_{KB}[B \backslash A]=\eta, \tag{1.5}$$

where the KB' denotes that the agent's epistemic situation has changed due to A (which may represent new knowledge or the deliverance of experience); and the symbol $\cdot\backslash\cdot$ denotes substantive conditional (or entailment) in the broad sense. This means that the precise quantitative formulation of $\cdot\backslash\cdot$ depends on its contextual interpretation. Some more examples are discussed next. The presence of a natural law signifies a causal connection between the entities A and B, in which case the $\cdot\backslash\cdot$ must account for the law. In the stochastic reasoning milieu, causality assumes various forms. Under certain conditions, a suitable choice of $\cdot\backslash\cdot$ is the material implication or conditional ($\cdot \rightarrow \cdot$) of formal logic, with one important difference. While in formal logic the $\cdot \rightarrow \cdot$ is content-free, stochastic reasoning assigns to it context and content, and then proceeds with the relevant probabilistic calculations. This basic stochastic reasoning feature would eliminate certain paradoxes of formal logic.[21] For example, in formal logic the $A \to B$ is valid even if the A and B are contentually irrelevant, which can lead to counter-intuitive results.[22] Stochastic reasoning avoids such pitfalls, since the corresponding entities of material implication are basically linked via a natural law and, hence, they are contentually relevant.[23] Another interpretive possibility concerning $\cdot\backslash\cdot$ is also of significant interest. If the occurrence of a mental state implies a causal link between the entities A and B, the symbol "$B\backslash A$" could express a logical counterfactual (if A hadn't happened, the B wouldn't either) so that $P_{KB}[B\backslash A] > P_{KB}[B]$. Other substantive options exist in regard to the interpretation of $\cdot\backslash\cdot$, which are examined later in the book.

1.2.3.5 Inference Under Conditions of Uncertainty

As far as real-world *inference* is concerned, stochastic reasoning replaces the rigidity of the classic logic process with the flexibility of the stochastic reasoning process. Let us consider an example. It is true that (Chapter 6)

$$If\ A\ \therefore\ B,\ then\ U_{KB}[B] \leqslant U_{KB}[A], \tag{1.6}$$

where the symbol "$\therefore$" means "logically entails," and U_{KB} denotes the uncertainty of the agent's assertion concerning A or B.[24] Equation (1.6) implies that in order to demonstrate the invalidity of the inference $A \therefore B$, instead of showing that A can be true but B false (which may involve searching a large number of possible scenarios), one merely needs to show that the inequality in Eq. (1.6) is violated (i.e., $U_{KB}[B]$ can be high, whereas $U_{KB}[A]$ sufficiently low). For illustration purposes, let $X_{\boldsymbol{p}_i}$ and $Y_{\boldsymbol{p}_j}$ denote two natural attributes (say pollution exposure and population mortality, respectively) at space–time points with coordinates $\boldsymbol{p}_i = (\boldsymbol{s}_i, t_i)$ and $\boldsymbol{p}_j = (\boldsymbol{s}_j, t_j)$, respectively; as usual, the vectors $\boldsymbol{s}_i$, $\boldsymbol{s}_j$ denote spatial locations, and the scalars t_i, t_j time instants (Chapter 4). Assume attribute probabilities between 0 and 1, and let $A =$ "$X_{\boldsymbol{p}_i} \to Y_{\boldsymbol{p}_j}$" and $B =$ "$X_{\boldsymbol{p}_i} \leftrightarrow Y_{\boldsymbol{p}_j}$," where $\cdot \leftrightarrow \cdot$ denotes the equivalent conditional of formal logic. In this case, the invalidity of $A \therefore B$ is easily shown in a stochastic sense, since it is valid that (Chapter 6) $U_{KB}[X_{\boldsymbol{p}_i} \to Y_{\boldsymbol{p}_j}] < U_{KB}[X_{\boldsymbol{p}_i} \leftrightarrow Y_{\boldsymbol{p}_j}]$. The foregoing accounts collectively suggest that one should clear up the inner essence of a problem before deriving a solution.

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[21] In this sense, one is not arguing against standard logic, but rather pointing out the need of a broader view that encompasses uncertainty.

[22] Say, "$A =$ Venus is made of feta cheese," and "$B =$ There exists life on Earth".

[23] Say, A and B denote hydraulic gradient and conductivity, respectively, linked via Darcy law (Table 1.1).

[24] Since uncertainty is defined as $U_{KB}[\cdot] = 1 - P_{KB}[\cdot]$ (Section 4.5), (1.6) is equivalent to $P_{KB}[A] \leqslant P_{KB}[B]$.

1.2.3.6 The Symbiosis of Natural Laws and Stochastic Logic

Stochastic reasoning suggests a *symbiosis* of the laws of Nature and the associated logic in the form of an integrated whole that reconciles the world of meaning with the world of natural law. To consider a law is at the same time to establish this law in thought and language, to incorporate it into a pre-existing worldview. This state of affairs is, in a way, similar to the viewpoint expressed by Steven Weinberg (1977: 149) that there is a "parallel between the history of Universe and its logical structure." Moreover, stochastic reasoning assumes a close interaction between matters pertaining to the content of knowledge, and the way knowledge is acquired and understood by an agent (through observational powers toward factual reality, and imaginative powers). In addition to descriptions of natural phenomena in terms of logic, depending on the context and content of the in situ situation, stochastic reasoning includes descriptions in which formal logic is not sufficient (e.g., when facing an inconsistent set of propositions, formal logic will tell us that some of them have to be abandoned, but will not tell us exactly which these are; Section 3.6.4). Instead, one needs to resort to *logic-external* substantive considerations (empirical, pragmatic, or semantic).

1.2.3.7 Experiment and Theory

As far as stochastic reasoning is concerned, experiments do not test a theory alone. Actually, what they test is the theory *together* with the assumptions linked to the experimental setup. As will be elaborated in Section 3.6, a distinction can be made between core (or general, or background) KB, G, and specificatory (or site-specific, or case-specific) KB, S. Consider the attribute $X_{\boldsymbol{p}}$ of Eq. (1.2), and let S_1-KB: *Experiment* E_1 *reports that* $\chi_{\boldsymbol{p}} \in I$.[25] In the real-world, the E_1-*based* probability of $\chi_{\boldsymbol{p}} \in I$ can be generally different than the *actual* probability of $\chi_{\boldsymbol{p}} \in I$. Standard probability applications assume that $P_{S_1}[S_1] = P[\chi_{\boldsymbol{p}} \in I] = 1$, where the former probability is relativized to the S_1-KB and the second probability is non-relativized to any epistemic situation but is a characteristic of Nature (the probability equality is assumed, e.g., when the actual probability is unknowable). A probability considered in the G-KB context, say $P_G[X_{\boldsymbol{p}} \leqslant \chi_{\boldsymbol{p}}]$, can change in light of S_1-KB. Accounting for the site-specific KB S_1, and using Eq. (1.5) where $\cdot\backslash\cdot$ is interpreted as the statistical conditional $\cdot|\cdot$ (Section 6.3), the updated probability is $P_G[(X_{\boldsymbol{p}} \leqslant \chi_{\boldsymbol{p}})|S_1]$, which is generally different than $P_G[(X_{\boldsymbol{p}} \leqslant \chi_{\boldsymbol{p}})|(\chi_{\boldsymbol{p}} \in I)]$. An interesting result is obtained if, in addition to S_1-KB, the investigator considers a second experiment, S_2-KB: *Experiment* E_2 *reports that* $\chi_{\boldsymbol{p}} \in I$. The probability equation $P_G[(X_{\boldsymbol{p}} \leqslant \chi_{\boldsymbol{p}})|(S_1 \wedge S_2)] = P_G[(X_{\boldsymbol{p}} \leqslant \chi_{\boldsymbol{p}})|S_1]$ is valid if one assumes that the probability of $\chi_{\boldsymbol{p}} \in I$ is 1 (which, though, may be not

[25] The I denotes an interval of possible attribute values.

valid in general). The above stochastic reasoning results are briefly presented here to whet the readers' appetite. The following chapters will discuss the matter in greater detail.

Before leaving this section, I would like to notice that by gaining a better understanding of their own cognitive means, argumentation modes, methodological underpinnings, and uncertainty sources, rational agents can improve scientific reasoning in a flexible (stochastic) rather than a rigid (deterministic) setting. This is a bold conclusion that allows imagination, ranging from the development of scientific theories to everyday intuitions about the world, to shape an agent's most fundamental sense of reality and proportion.[26]

1.2.4 The Good, the True, and the Beautiful

In connection to the methodological points made above, many significant advances in science are characterized by rational thought that takes conceptual account of what has been experienced. Accordingly, in sciences the two worlds of Parmenides became the way of reason (rationalism) and the way of the senses (empiricism).[27] How to meaningfully and efficiently integrate these two ways of thinking into the IPS process is a major focus of Epibraimatics. Therefore, when studying natural systems, one needs to first carefully distinguish and then properly integrate into the IPS process: (*a*) empirical questions linked to factual evidence, explanatory theories, and prediction models (questions that are primarily the concern of sciences); and (*b*) conceptual questions concerning the meaning of mental constructs, the validity of the representational forms, and the structural relationships between different abstract fields (these questions are primarily the province of philosophy). In a sound IPS framework, conceptual issues are presupposed by scientific investigation, experimentation, and theorizing. This fact has two significant consequences. First, if the conceptual clarity of the empirical and theoretical components of the in situ problem is not adequately addressed, the solution process can be seriously misguided, and its results utterly misinterpreted and misused. Second, conceptual issues usually are not amenable to scientific investigation, experimentation, and theorizing. This happens because the conceptual issues are concerned about what does or does not make sense rather than about what is or is not empirically valid.

Given the prime importance of the above distinction, its potentially serious consequences have been well documented. Among others, the neuroscientist Maxwell Bennett and the philosopher Peter Hacker joined their voices to call our attention to empirical versus conceptual matters: "When a conceptual question is confused with a scientific one, it is bound to appear singularly refractory. It seems in

[26] Conceptual intellection and innovative methodology are not always viewed as basic prerequisites of human inquiry by the modern academic elites (see, Section 1.5). A case in point is the rapid decline of many academic departments that urgently need the oxygen of sound thought and creative imagination.

[27] The readers have been briefly introduced to rationalism and empiricism in Section 1.1.2.

such cases as if science should be able to discover the truth of the matter under investigation by theory and experiment – yet it persistently fails to do so ... Any unclarity regarding the relevant concepts will be reflected in corresponding unclarity in the questions ... in the design of experiments intended to answer them ... in the interpretation of the results of experiments" (Bennett and Hacker 2003: 5).

The more one becomes familiar with the *daedalic* yet fascinating territories of human inquiry, the more one realizes that a number of conceptual and empirical issues will continue to challenge the human strains of thought and creative imagination for many years to come. But as the goddess revealed to Parmenides at the *Gate of Night and Day*, this may be the only way for Man to survive and bring oneself closer to the ultimate goal of "The good, the true, and the beautiful" and, hence, to enable Man to reflect constructively on the most significant of life's questions (such as, what it means to become good, how one searches for truth, and how one appreciates what is beautiful).

1.2.5 The Broad Context of IPS

It is time to consider IPS in a broad context. Undoubtedly, there is continuity in scientific problem-solving, which evolves within a historical era characterized by culture, ideology, and tradition. It should be pointed out that *tradition* is not the mere repetition of the past, but a conscious participation in the worldly experience and understanding of the past, a disposition to learn from its substantive achievements, and to assimilate and enhance them with full awareness of the present demands (practical and intellectual). It includes the appreciation of what Martin Heidegger called "a past that still continues and gathers itself into something remaining so it can give itself anew to those who await." Without being necessarily limited by them, it will be ridiculous to ignore the great achievements of the past. If they are ignored, every domain of knowledge will have to start from the beginning, continuously being in a state of infancy. Albert Einstein, e.g., did not just appear out of nowhere. Instead, he arose out of the physics tradition of the Enlightenment era that dates back to Isaac Newton or earlier. Accordingly, a modern investigator should be able to distinguish between three basic levels of analysis: (*a*) The *ontic* level of analysis, which is concerned with what exists in the real-world and the nature of what exists. Hence, at this level the IPS investigators are interested about which statements about in situ entities (objects, processes, phenomena, attributes) are true, and their relations. When the investigators are trying to determine which laws of Nature exist, and what they are in and of themselves, they are working at the ontic level. (*b*) The *epistemic* or *theory of knowledge* level of analysis, which is concerned with what humans can know and how, including the nature, meaning, scope, and reliability of knowledge. When the investigators are trying to determine how humans are justified in believing in the laws of Nature, or justifying anything about these laws, they are working at the epistemic level. (*c*) The *sociology of knowledge* level of analysis, which is concerned with the study of the relationship between scientific thinking and the social environment within which it arises and evolves. Otherwise said, this level of analysis views science as a social activity, and studies the social conditions and effects of science, and, also, the social structures and processes of scientific activity. Of prime importance at this level of analysis is to understand what kinds of knowledge are possible given the social environment, what kinds of research this environment encourages versus research that it discourages or even forbids.

Investigators who, as a result of their education and professional expertise, focus at one level of analysis ought to be aware of the crucial links between this level and the other two levels. For example, when investigators try to understand how one can know a truth about an entity of the real-world (epistemic level), they presuppose that this truth about the entity exists (ontic level); otherwise, it would make no sense to try to understand something that does not exist. Also, the investigators need to be aware to what extent the knowledge they seek are knowable or acceptable by the social environment, if they want to protect themselves from unpleasant surprises and, in a way, avoid "building castles in the air." In the same context, the investigators must be able to distinguish between a technically successful problem–solution, and a solution that makes a positive social impact. The current era of Decadence affects all three levels of analysis above, and exerts a major effect on human inquiry, which is a fact that needs to be taken seriously into account when studying an in situ IPS situation (with its concepts and methods, multidisciplinary knowledge sources, thinking modes, problem formulation, and solution's objectives). In such circumstances, the investigators' reaction should be to expose themselves to a wider culture, and a richer domain of ideas, without necessarily assuming the role of "public intellectual" in a society in which entertainment is the name of the game. In fact, the deeper understanding of some of the main facets of Decadence that will be attempted in the following sections is not aiming merely at a sociopolitical analysis of the phenomenon of Decadence per se. Rather, such an understanding is essential in the realistic consideration of many scientific problems and their possible solutions, because the broad environment within which the problems emerge can very well affect their solution.

1.3 A Time of Decadence

In light of the analysis in the previous lines, the readers may excuse a rather necessary diversion. It is widely admitted that the world is in a time of *Decadence* that is the result of the intellectual poverty, blatant opportunism, and squalid motives that characterize most power holders that dominate societies at a worldwide scale. The decomposition of a society may be seen especially in the disappearance of significations, the almost complete evanescence of values. Recent works that masterfully describe certain key aspects of Decadence are Susan Jacoby's (2009), Chris Hedges' (2009), and Janine R. Wedel's (2009) books. Earlier and rather prophetic works include the books of Eric Havelock (1951), Jacques Barzun (1959), and Richard Hofstadter (1963). Many studies consider corporatism a major contributor to Decadence (Korten, 2001; Rushkoff, 2010).

Corporatism has a long history in the West that extends over several centuries; a turning point in the evolution of its modern phase was the degeneration of the so-called “social capitalism of Rhine” to the “casino capitalism” of the post-war economic model in Europe. Corporatism is responsible for the financial demise of many people and institutions as well as for some of the worst environmental disasters in history. For example, the readers are surely aware of the recent oil spill in the Gulf of Mexico caused by BP (British Petroleum), the largest ever oil spill in U.S. waters that led to the loss of 11 lives (Gold et al. 2010).

1.3.1 Investigator Awareness

As noted earlier, investigators can be effective problem-solvers only by cultivating constantly an open sensory awareness that covers all thinking and acting that take place in their surroundings. Awareness of the broad environment, not isolation within the strict boundaries of a technical expertise, can help investigators better channel their research efforts, and avoid wasting valuable time. Understanding the environmental (institutional, epistemological, social, and cultural) determinants of thought and problem-solving is indispensable to liberating the investigators’ creativity and freedom of thought from the determinisms of the “order of things” as imposed on them by the ruling elites. Section 1.4, e.g., shows that an intellectually corrupt environment can dictate a shadow epistemology on scientific inquiry and the IPS process, with potentially disastrous results for the investigator and the society at large.[28] Hence, the investigators must be aware of the trade-offs they inadvertently make as they tolerate, even approve of, this state of affairs. Ignoring these real-life facts not only would be a professionally naïve decision, but also a dangerous attitude toward life. In sum, investigators with a wide educational background and constant awareness of the broad environment (social, political, economic, and cultural) within which they operate are more valuable to themselves and their scientific fields, and, also, more useful to the public. In a certain way this suggests that one should be *in* the system but not *of* it.

In an effort to impress the above points on the readers’ minds, some parts of the book need to aim at named institutions, established systems, and organized groups. This kind of approach always involves a certain amount of personal risk. But if the criticism is not directed at specific entities that affect people’s lives and professional development, then what should be directed at? At windmills, like modern *Don Quixotes* would do? That would be a waste of time, and the height of cowardice. Not to mention that in the era of political correctness, there exist enough of harmless social exercises already, and more of them would not add anything worth the readers’ attention.

[28] Many experts argue, e.g., that the shadow epistemology imposed on cancer research by financial interests has reduced considerably the chances to better understand and cure the disease.

1.3.2 From Ancient to Modern Barbarians

In the preface, I used the term *clerkdom* to describe the ruling elites, powers that be, and cabals that dominate many aspects of culture (social, political, economic, scientific, etc.), and share a large part of the responsibility for the crisis of the epoch and the decadent spirit of the times. As we shall see in the following pages, in order to serve its dubious motives and suspect agenda, the clerkdom has created a system that is flexible for the insiders but rigid for the outsiders. Human values and principles are not the main concern of the cynical power holders. Their damaged worldview manifests a deep terror of candour and meritocracy, strongly opposes any kind of intellectual debate[29] and constructive criticism and, instead, it shows a systemic preference for a culture of appearances, deceit, greed, and casual mendacity. Among the most trusted devotees of the clerkdom are proponents of consumerized education and corporate science. *Mutatis mutandis*, some of these individuals nowadays play the role of the ancient barbarians who burned libraries (Section 1.1.1).'Being faithful to their ancestors' rituals, modern barbarians attack original thought and intellectual innovation every time they are given a chance. At the same time, their own work is noticeably shallow, lacking any kind of originality and creativity. And their imagination is dangerously limited, resorting to nothing but "clichés." It is not surprising that for modern barbarians any reference to truth and meaning is the ultimate conversation stopper. The readers are reminded of the recent example of top BP executives who for weeks refused to face the truth concerning the worst environmental disaster in U.S. history caused by their company's activities. Characteristic of the corporatism ethos is that while the situation in the Gulf of Mexico was worsening by the hour, the company's CEO, apparently untouched by the tragedy, continued enjoying his sailing trip (Kennedy, 2010).

Future historians tracing the origins of the curious phenomenon of the clerkdom will undoubtedly detect the prominent role of careerism and greed. But the clerkdom is not merely greedy – it is an actual impediment to progress. Being well aware of their remarkable inability to produce work that is novel and correct at the same time, the ruling elites confront with cynicism any kind of innovative work and express suspicion about the motivation of its creators. One can find a plethora of cases in history where noblemen and noblewomen of thought were engaged in brutal battles against the most vicious forms of power holders, although nothing resembles the current phase of Decadence. Among the most famous cases of the past are the struggles of Socrates and Galileo against the Athenian political establishment and the Vatican Inquisition, respectively (a comparative analysis of the different cases of these two giants of thought will be attempted in Section 10.3). One of the lesser known yet most tragic cases is that of Hypatia,[30] who was brutally

[29] In the western world the kind of debate that seems to attract global attention nowadays is that concerning the rate of Euro versus U.S. dollar.

[30] Hypatia (*Υπατία*), who lived in the late AD fourth to fifth, is believed to be the sole woman represented in Raphael's 1511 painting *The School of Athens*.

murdered by the fanatics of the Alexandria patriarchy. Hypatia was yet another devoted intellectual, who paid the ultimate price for defending her values and ideals (Section 3.6.4). In more recent times, the reader may be aware of Ludwig Boltzmann's tragic fate. Boltzmann, who was one of the greatest physicists ever lived, committed suicide deeply disappointed by the nineteenth century scientific elite's rejection of his pioneering work (Section 2.3.1). Albert Einstein repeatedly emphasized the negative effects of hostile social environments on innovation and creativity: "Few people are capable of expressing with equanimity opinions that differ from the prejudices of their social environment; most people are even incapable of forming such opinions." Bertrand Russell was an influential philosopher, mathematician, and logician as well as an important political liberal and activist. To his lasting credit, Russell created many enemies inside the clerkdom of the time for his strong stand in favor of human rights and freedom of thought. Yet another characteristic case is the brilliant mathematician Norbert Wiener, whose path-breaking ideas were met with strong opposition and bitter criticism by the ruling elites. Wiener famously confessed that (Conway and Siegelman 2006: 55), "I was quite aware that I was an out among ins and that I would get no shred of recognition that I didn't force. If I was not to be welcomed, well then, let me be too dangerous to be ignored." Charles Sanders Peirce, America's most original philosopher and a leading scientist, was denied professorships at both the Harvard University and the John Hopkins University, because of conflicts with powerful benefactors and supporters (Crease 2009: 39). Referring to the profound incompetency of the self-appointed academic elites, James K. Galbraith came to the sad conclusion: "Is not that there has been no recent work into the nature and causes of financial collapse. Such work exists. But the lines of discourse that take up these questions have been marginalized, shunted to the sidelines within academic economics. Articles that discuss these problems are relegated to secondary journals, even to newsletters and blog posts. The scholars who betray their skepticism by taking an interest in them are discouraged from academic life – or if they remain, they are sent out into the vast diaspora of lesser state universities and liberal arts colleges. There, they can be safely ignored" (Galbraith 2009: 87). Lastly, representative of clerkdom's triumphant cynicism and shameless opportunism is the comment of a Caltech administrator concerning the professional fate of the eminent string theorist John Schwarz: "We don't know if this man has invented sliced bread, but even if he has, people will say that he did it at Caltech, so we don't have to keep him here" (Mlodinow 2001: 254). If John Steinbeck was alive and wanted to describe the current academic environment, he might have considered writing a novel titled *Of men like mice*.[31] Under the circumstances, nobody should have been surprised when A. Schlesinger Jr. made the rather strong statement: "Anti-intellectualism has long been the anti-Semitism of the businessman. The intellectual is on the run today in American society" (Hofstadter 1963: 4). Yet, against all odds, with

[31] Steinbeck won the 1962 Nobel Prize for Literature. Among his best-known novels is *Of men and mice*.

the stones the ruling elites cast at them, geniuses like Socrates, Galileo, Boltzmann, Peirce, Russell, and Wiener have managed to build new roads for them and the humanity at large. This is the ultimate insult to the elites.

1.3.3 The Disregard of History

In general, *History* is important for human beings, since they live in its consequences (e.g., concepts, institutions, traditions, and norms are all history's legacies). As far as IPS is concerned, history is a potentially significant contributor to it, given that many real-world studies rely on historical information. Characteristic in this respect is the study of the fourteenth century Black Death epidemic, which was based predominantly on historical data, see Fig. 1.2 (Christakos et al. 2005). Fascinating discussions of one of the worst epidemics ever recorded in the world's history can be found in Wang (2005), Bossak and Welford (2009), and Gummer (2009). Given the situation with the phase of Decadence we are in, it is not surprising that the powers that be have a profound disregard for History, but still rush to take advantage of its most valuable products when the opportunity arises.

1.3.3.1 The Thieves of Baghdad

A typical example of this apparent contradiction is that, while modern barbarians aggressively question

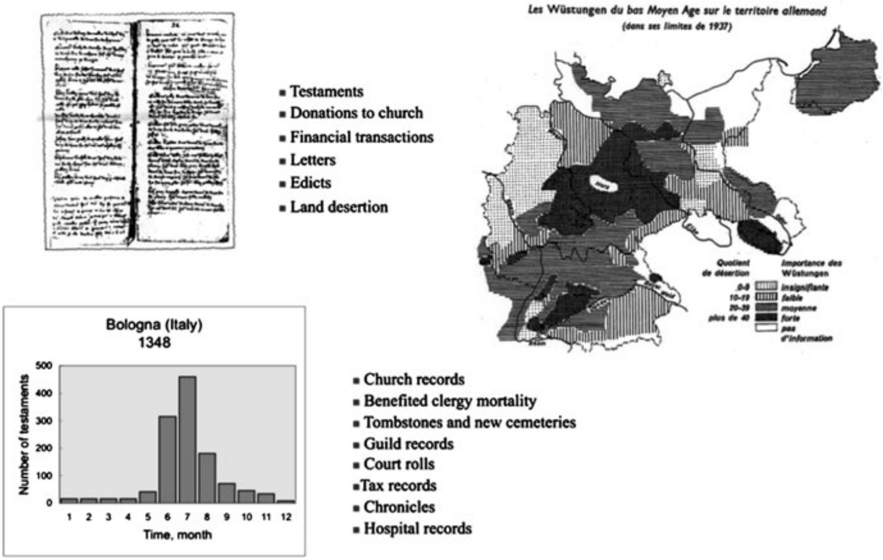

Fig. 1.2 Historical data used in the Black Death epidemic study (fourteenth century Europe)

> Why a bunch of old rocks with funny writing matter so damn much

(Bogdanos 2005: vi),[32] yet like the modern thieves of Baghdad – who stole such rocks and other priceless antiquities from the Iraq museum for financial profit – they shamelessly trade the intellectual achievements of others and profit from them.

This is hardly surprising in lieu of the fact that clerkdom's approach has always been to capitalize on its unique combination of opportunism, impudence, and greed. Like cows, the wandering elites of the clerkdom have always grazed on the pasture of knowledge produced by others, who usually happened to be the clerkdom's own victims. Yet, they strongly oppose new ideas and progressive thinking. It is the same kind of elites that in the past fought against dissecting cadavers to understand how human body works or against studying the heavens. Perhaps, a key element of the current crisis of corporatism is that this vampire system is running out of victims and their significant innovations, ideas, and intellectual achievements that the system needs to feed on in order to survive. It is a case of self-destruction that characterizes all parasitic systems. In the words of Douglas Rushkoff (2010: xxi), "As searing new books and documentaries about the crimes of corporations show us, the corporation is itself a sociopathic entity, created for the purpose of generating wealth and expanding its reach by any means necessary."

1.3.3.2 Torah's Worry of Leaders

In international politics, disregard for History was loudly echoed in Condoleezza Rice's[33] statement regarding the ancient Macedonia name dispute (Papachelas 2008):

> It would be a pity if something that has to do with antiquity were to get in the way...

An apparently "politically correct" statement that serves as an excuse for cruelty and injustice. The careful reader may detect a close similarity between Rice's disdain of matters of antiquity and the sediment reflected in Bogdanos' comment about ancient rocks. As sad as it is, still it is hard to believe that someone who served as a high-level administrator in both the academia and the government of a nation that aspires to be the world leader shows such a blatant disrespect for History. Alas, when the clerkdom claims a leadership role, one should be reminded of Torah's *Worry of Leaders*!

The multi Pulitzer Prize winning author Thomas L. Friedman has protested the sad state of affairs at the top of political leadership (Friedman 2007: 379): "We have way too many politicians in America today who seem… to go out of their way actually to make their constituents stupid." Similar is the view of Lewis H. Lapham

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[32] U.S. Marines colonel Matthew Bogdanos' book is a fascinating reading that describes his team's monumental efforts, amidst the ruins of the 2003 invasion of Baghdad, to recover some of the world's most important antiquities stolen from the Iraq museum.

[33] During 2005–2009 Rice was the U.S. Secretary of State. From 1993 to 1999, she served as the Provost of Stanford University (California).

who writes about the political elites: “Why would any politician in his or her right mind wish to confront an informed citizenry capable of breaking down the campaign speeches into their subsets of supporting lies?” (Lapham 2008b: 18). The disrespect of History is widespread even in countries whose main asset is History itself. Greece, which boasts to be the “Cradle of Democracy,” and is a member of the European Union (E.U.), basically does not allow its citizens to express themselves in an active manner through referendums and initiatives – the main ideas of Democracy as envisioned and practiced in classic Athens of the Golden Age. In modern Athens of the Decadent Age, the ruling elites (politicians, media, and financial interests) use all sorts of sophisms and tricks to deprive citizens of their most basic democratic rights.

History’s lesson for noble thinkers is to avoid the clerkdom’s influence. This must be done, even if it appears to be offensive to some. Because as Lord Reith remarked, “There are some people whom it is one’s duty to offend.” Lord Reith’s suggestion is fully justified by the additional reason that, in many respects, the clerkdom’s ideology is Hegelian in its most brutal form. This is an ideology that institutionalizes a subject–object relationship enabling a reduction in the definition of the human being to something complying in the end with the official clerkdom ideology that decides who deserves recognition, promotion, and support.

1.3.4 *Corruptio Optimi Pessima*[34]

A signature case, indeed: People who were once decent and creative individuals are obliged to operate within a corrupted environment, and degrade themselves by adopting the damaged belief system and behavioral mode of the power holders. The belief system and behavioral mode of these individuals naturally characterize the solutions they propose for a real-world problem (the data sources they selectively take into account, the conditions they impose on the respective disciplines, the self-serving goals they set, and the methodology they chose).

1.3.4.1 The Myth of the People

If corruption of the best is worst, the truth is that in many cases the people actually share a large part of the responsibility by being either indifferent observers or conscious contributors to the widespread corruption. As a matter of fact, one must find the courage to abandon the so-called Myth of The People who do not share any responsibility for this sad state of affairs (Schenkman 2009). Particularly

[34] Corruption of the best is worst.

enlightening is Polly Toynbee's analysis of the British voter:[35] "They [Labour party] have abandon their view of the voter as a decent sort and adopted the Tory model of the voter as selfish, lying bastard." Many people often embrace irrational argumentation, and base their opinion on myths and lies rather than objective facts. Demagogues, crooks, tyrants, and opportunists of all sorts know very well how to take advantage of this reality. Which brings to mind what Nikita S. Khrushchev had to say about the matter: "If the people believe there's an imaginary river out there, you don't tell them there's no river there. You build an imaginary bridge over the imaginary river."

It is a fact of life that more often than not people willingly fall into the trap of "easy living" that keeps them in a state of perpetual consumerism encouraged by the mass media and their patrons. This includes the need to consume shapes other practices and activities. There is a consumer relationship between the human agent and education, art, even religion. Many people "don't actually want to be informed, and even less so challenged in their beliefs and worldview. Rather they wish to see a champion defending their preconceived view of the world" (Pigliucci, 2010: 110). An increasing number of people avoid to subject themselves to the *βάσανο*[36] of serious thought and introspection. They would rather let others do their thinking for them, which may be the answer to Susan Jacoby's question (Jacoby 2009: 25): "A majority of adults, in what is supposedly the most religious nation in the developed world, cannot name the four Gospels or identify Genesis as the first book of the Bible. How can citizens understand what creationism means, if they cannot even locate the source of the creation story?" When faced with a choice between the harsh truth and a comforting fiction, many people chose to embrace the latter. Characteristic of the situation is that (Schenkman 2009: 17, 123), "No one thing can explain the foolishness that marks so much of American politics. But what is striking is how often the most obvious case – public ignorance – is blithely disregarded. Like the classical clue in many an Edgar Allan Poe mystery it remains hidden in plain sight;" and "there is damning, hard evidence pointing incontrovertibly to the conclusion that millions are embarrassingly ill-informed and that they do not care that they are."[37] As a result, the ethically challenged elites continue to command people's respect even after their corrupt means have been exposed, and sometimes they garner more respect and downright admiration for their "skills" and sheer nerve.

Alas, contrary to the "Myth," many people are willing to lie in order to achieve their goals, and are eager to cajole those in power, because their objective is not to change the corrupted system, but rather to improve their own access to it so that they can participate in a life of material privilege and ease. According to Sissela Bok (1989: 23), "It is crucial to see the distinction between the freeloading liar and

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[35] Polly Toynbee, *Guardian*, 27 November 1996.

[36] The word *βάσανο* (vasano) is found in the *Old Testament*, and it means the uncomfortable state caused by serious thinking and deep reflection.

[37] The Iraq war, the 9/11 disaster, and the anti-evolution movement, among many other examples, offer enough evidence that people can be easily manipulated and misled by misinformation and fear.

the liar whose deception is a strategy for survival in a corrupt society." It may sound cynical, but this is often the case even among people who seem to criticize the system, but whose real motivation is a covert desire to become part of the (socially and financially profitable) corruption. The canniest among these people manage to trick and blackmail themselves into the system. As soon as they are allowed to enter the club of the privileged, they forget everything they have said before against the system and become its most fanatic supporters. Sadly, this is yet another instance of a disillusioned and cynical public life in which truth is increasingly becoming indistinguishable from falsehood.

1.4 The Shadow Epistemology

The readers may find it noteworthy that beyond the cognitive classifications of knowledge considered in Section 1.1.3, there are also knowledge classifications shaped by sociopolitical forces and motivated by agenda power. A central doctrine of the Enlightenment was that the universal spread of truth is the great liberator of humankind. This doctrine echoed Jesus' teaching: "You shall know the truth, and the truth will make you free." Truth is making men free, indeed, but it is also frightening to death the clerkdom and the ruling elites, which often include significant numbers of radical postmodernists, especially in higher education (Section 1.5). Therefore, sharply distinguishing itself from humankind's quest toward gaining true knowledge, clerkdom's high priority is to establish a *shadow epistemology* that promotes its absolute control of the generation, transmission, and communication of knowledge. As such, shadow epistemology is at the service of the hidden forms of domination and exploitation that shape socio-historical reality. The proponents of shadow epistemology are not seekers of truth. On the contrary, they promote low intellectual standards and even meaninglessness in people's lives, while at the same time they embrace the enigmatic maxim of Baltasar Gracian: "The truth is for the minority." Which is why shadow epistemology would be better characterized as a pseudo-theory of knowledge, whose sole purpose is to serve the dubious interests of corrupted minorities, usually belonging to the privileged sections of the society.

The above can have grave implications in real-world IPS. Every problem–solution underlies a certain epistemology, which means that the quality of the solution is closely linked to that of the epistemic standards (such as knowledge reliability, truth value, honest inquiry, and internal consistency). When what underlies a problem–solution is the pseudo-theory of knowledge represented by shadow epistemology, one should be prepared for the worst, regardless of the level of sophistication of the tools (analytical, computational, and experimental) used in the solution of the problem.[38]

[38] If, e.g., the main goal of corporate pharmaceutical research is financial profit, it is doubtful that the power holders will allow the search for innovative solutions that can cure certain diseases but reduce their profits (often linked to the prolonged treatment of diseases).

1.4.1 Insiders Versus Public Domain Knowledge

Shadow epistemology introduces various gradations of knowledge and truth, and the ways of communicating them to the public. Enlightening in this respect is the view of a prominent member of the neoconservative elite, Irving Kristol: “There are different kinds of truth for different kinds of people. There are truths appropriate for children; truths that are appropriate for students; truths that are appropriate for educated adults, and the notion that there should be one set of truths available to everyone is a modern democratic fallacy. It doesn’t work.” (Oborne 2005: 184).[39] It is then not surprising that power holders purposefully distinguish between two major knowledge bases: The “public domain” base that is considered safe or appropriate for public display, and the “insider domain” base that dare not be articulated except among the nomenklatura of the clerkdom and its most trusted devotees. While not all elites create the same level of tension between the revealed (public domain knowledge) and the hidden (insider domain knowledge), the basic element of distance is common to all of them.

The insiders’ knowledge base involves complex strategies of encoding and communication that enable the transmission of key information to the ruling elites only. The insiders of an elite (e.g., in science) often communicate among themselves using their own *hermetic*[40] *jargon* as a way to defend barriers and avoid any kind of scrutiny and criticism of its activities by outsiders and the public. Talking about education elites, Hedges (2009: 89–90) maintained that “The established corporate hierarchies these institutions[41] service – economic, political, and social – come with clear parameters, such as the primacy of unfettered free market, and also with a highly specialized vocabulary. This vocabulary, a sign of the ‘specialist’ and, the elitist, thwarts universal understanding. It keeps the uninitiated from asking unpleasant questions. It destroys the search for the common good.” Hence, only the elites of insiders have full access to all sources of crucial information in a timely yet esoteric manner; and as is usually the case, those who hold the information also get to interpret it. Since knowledge is power, these insiders put themselves in a center of great influence. Those “in the know” are presented with greater opportunities for influence, which allows them to have an iron grip on the government, key positions, critical resources, and the like. The anthropologist Janine R. Wedel (2009) describes how a variety of well-informed and well-connected manipulators, ranging from Harvard economists to Wall Street high flyers, operate mainly behind the scenes

[39] If nothing else, one wonders whether Kristol and others like him had ever considered the confusion, miscommunication and hostility among groups of people who assign different truths to the same phenomenon; or the possible psychological damage caused to human beings exposed to various truths during different phases of their lives (e.g., one “truth” about human existence during one phase, a contradicting “truth” in another phase, and yet a different “truth” at a later phase).

[40] “ Hermetic” is an ancient Greek word that means airtight sealing.

[41] The author in his text refers to institutions like Harvard, Yale, Stanford, Cambridge, and Oxford.

and break every rule of accountability to accomplish their own goals. Wedel charts how the self-appointed elites collect and accrue vital knowledge bases, which can be used to lobby the government and key politicians in order to take over major institutions and agencies of strategic importance.[42]

On the other hand, public domain knowledge is under the strict control of the same elites that decide which information sources and key documents are kept secret from the public. As a consequence, the number of important subjects about which citizens have a clear and well-informed opinion is tiny. Special interests often finance advertising campaigns that are supposed to inform the public about important issues, but in reality they are part of a carefully designed plan to misdirect and shape public opinion in their favor. As such, public domain knowledge may include outdated knowledge, and various untrue statements made by the ruling elites (politicians, advertisers, scientists, administrators, economists, entertainers, and the mass media) and distributed among the public for purposes of manipulation. In many cases, these are sort of opportunistic lies, some of them are so-called white lies, but a significant number of the statements are the result of systemic deceit. Consider America's war in Vietnam (1960s–70s). At that time a crucial hypothesis was *H* = *The war is won*. Along the lines of shadow epistemology, political and financial elites early on declared: *G* = *The public should be assured that H is correct*. In stochastic terms (Section 1.2.3) this epistemic situation would imply that the probability *P[Public opinion sypporting H given G]* = P_G *[H]* was high. Soon afterwards the public was informed that *S* = *Experts strongly argued that evidence showed that* ¬*H*. Washington elites responded that *A* = *The analysis of the experts is flawed*. Accordingly, the public was presented with two options: (1) To trust the experts that *A* was not true, in which case P_G *[H given S and* ¬*A]* = P_G*[H given S]*≪P_G*[H]*, i.e. the probability of *H* was small. (2) To believe the elites that *A* was true, implying that P_G *[H given S and A]* P_G*[H]*, i.e. the chance of *H* was high. As was proven later, (1) rather than (2) was the correct assessment of the real-world situation. The rest is history. Massimo Pigliucci (2010: 32) paints a rather grim picture of reality when he talks about "Prominent politicians and media figures simply making lies to cynically further their positions. These tactics find such fertile ground precisely because most American citizens do not take a course in intellectual self-defense, with the result that the self-appointed 'greatest democracy in the world' may be a few steps away from collapsing into chaos and paralysis."

1.4.2 *Metarules: Cortigiani, vil Razza Dannata*[43]

To understand how an elite of the socially privileged thinks and functions, one needs to know shadow epistemology's *metarules* that determine how one must relate to

[42] It is telling that the elites' lobbying of the government is a highly expanding industry. The readers may be amazed to hear that just during the period 2000–2005 the number of registered lobbyists in Washington D.C. doubled to nearly 35,000 (Schenkman 2009: 78).

[43] Courtiers, you cowardly and damned race.

certain norms, and how to implement them (when to take matters literally, disregard them, pretend doing as a free choice something that is effectively an obligation, etc.). The metarules view individual or group behavior as a form of coded manifestation, intentionally concealing crucial knowledge sources that only the few can decipher.

The readers may recall a scene of mutual hypocrisy in Shakespeare's play *Hamlet*, in which Claudius and Hamlet "address each other with freezing, calculated politeness" (Asimov 1970: 91). In a similar vein, Ambrose Bierce characteristically maintained that politeness is the most acceptable form of hypocrisy. Little they knew that one of the clerkdom's prime norms of communication in the current corporatism era would be to *ex dolo* ritualize *calculated politeness* (CP), i.e. to impose on society the informal rule of considering it dangerously impolite to challenge the views of the ruling elite. This is the worst form of fake politeness, beyond anything the rich imaginations of Shakespeare, Bierce, and other distinguished writers could have ever conceived. It is the "politeness" of people who smile with their mouths but not their eyes. In some cases, CP is combined with irony. In *Politeness Theory* this is considered a multifarious phenomenon (it includes, e.g., "saying the opposite of what the speaker means;" Brown and Levinson 1987: 221). Those who dare make what the metarules system labels "impolite questions" are subject to the smear tactics of power holders, which, depending on the situation, vary from fake civility concerns to rude irony to vicious slander. The latter is sometimes related to certain forms of the so-called culture of fear in which clerkdom-controlled organizations and institutions thrive on scare and benefit from the exploitation of fear construction (Altheide 2002; Furedi 2005). In praxis, CP serves as the Trojan horse that disguises the operations of power and politics of the ruling elites. Indeed, resort to CP is absolutely necessary for these elites, for it often provides the prime means to silence their critics, and avoid exposing the system for what really is: corrupted, dishonest, insidious, deceitful, and self-serving.

The next norm brings to mind Rigoletto's famous aria "Cortigiani, vil razza dannata." This norm refers to the systematic promotion of *courtiership*, i.e. flattering those in power, and ingratiating oneself with anybody and everybody who could do one a service or grant one a privilege. The courtiership mentality is particularly widespread during the time of Decadence, when it becomes a socially accepted and widely desired activity, since it is one of the most effective means of social and professional advancement. Many individuals find their way in the world by means of their "plastic capability" and adeptness in the use of servility, in particular when it comes to dealing with funding agencies and influential committees (academic, professional, political, etc.). These courtiers know very well that in order to succeed, they often need to have the morals of a whore and the manners of a dancing master.

Another noteworthy norm is the carefully *self-appointed unaccountability*, i.e. creating a climate that allows the ruling elite to place itself above any kind of accountability. Even when proven blatantly wrong, the cloud of self-appointed unaccountability protects the elite from potentially damaging consequences. Unaccountability tactics include diverting attention away from oneself, distorting the truth, faking defiance, accusing others of misunderstanding, pretending superiority, introducing irrelevant material, and disclosing only what benefits oneself. As discussed in

Galbraith (2009), among the most amazing displays of dishonesty in recent history is the self-appointed unaccountability combined with the unimaginable arrogance of the top schools of academic economics: despite their demonstrable incompetency to respond to the greatest economic challenge of a generation, by masterfully implementing the tactics of calculated unaccountability, these elite schools managed to escape any major criticism that could damage their image and prestige. The reader should not forget that a birth-child of the uncountability norm is the notorious notion of "self-regulation" of the markets that has led to serious financial crises. Also, in the politics sector closely linked to the unnacountability norm is Tony Blair's infamous doctrine, "I know what I believe."[44] Rational people would rather say, "I believe what I know," implying that the meaning of the word "know" (defined as a justified true belief; Section 1.1.2) is epistemically more significant than that of a mere personal "belief." But rationality is not the concern of shadow epistemology. The consequences of Blair's doctrine are startling, since it allowed him to make whatever statement he liked "about Iraq, about weapons of mass destruction, or for that matter to attest that the moon is made of green cheese" (Oborne 2005: 137). In addition to the economics, finance, and politics sectors, unaccountability in the broad sense is an essential element of scientific solutions with very long-term perspectives. Nuclear waste risk assessment, e.g., often considers time horizons of several thousand years (Svenson and Karlsson 1989; Lee and Lee 2006).

Lastly, a norm of increasing importance in today's globalized world is *flexibility*. One finds "movers and shakers" who serve at one and the same time in different organizations, institutions, and states. Wedel (2009) calls this elite of influencers "flexians," who "are *in* these organizations (some of the time anyway), but they are seldom *of* them." The flexians have privileged access to key information that they deploy to their own ends (often for purposes that are neither in the public interest nor easily detected and regulated). The flexibility norm encourages elites to toy with what once used to be sacred rules of conduct, and even fashion new rules to benefit themselves. Taking advantage of the infinite tolerance of some modern societies, the flexians often serve in various interdependent and overlapping roles, which raises serious ethical issues. A characteristic case of flexian, e.g., is the investigator who manages a research project and at the same time serves as the EPA[45] peer-review leader for that project (see, also, Section 8.4.3).

1.4.3 The Straussian Worldview

Leo Strauss was one of those political philosophers who strongly rejected the Enlightenment doctrine. Instead, Strauss advocated that truth dissolves the bonds of society,

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[44] From his speech in the 2004 Labour party conference. Tony Blair's actual mode of argumentation was further elucidated by the British Chancellor Gordon Brown, who told to his Prime Minister that, "There is nothing you say to me now that I could ever believe" (Peston 2005: 349).

[45] Environmental Protection Agency.

and imposes too much burden on ordinary people, whereas knowledge belongs to a few. At the root of this esoteric view is the idea that social order will collapse under complete conditions of transparency (Drury 1999). No wonder that the systemic deceit of shadow epistemology finds theoretical support in the Straussian worldview. For Straussians, in turn, shadow epistemology offers a way of "protecting" the uninitiated public from the destructive power of truth. This "closed club" view of knowledge is a source of inspiration for different kinds of elites in politics, economics, and science. *Mutatis mutandis*, Straussian esotericism reminds one of the isolation of 18th century European kings from their people, which finally led to their tragic fall.

In Straussian politics, noticeable is the authoritarian embrace of the so-called noble lie, whereas truth telling is a matter of exercise of power. The latter apparently was the case of the neoconservative movement with enormous influence in American politics (Corn 2003). According to Irving Kristol (a student of Strauss), Strauss "was convinced that there was an inherent conflict between philosophic truth and political order, and that the popularization and vulgarization of these truths might import unease, turmoil and the release of popular passions hitherto held in check by tradition and religion with utterly unpredictable, but mostly negative, consequences" (Bailey 1997). The shadow epistemology also characterizes the "third-way" politics in UK that elevated Thatcherism into a postmodern conceptual level – see the perceptive analysis of Peter Oborne (2005). As has been noticed by Colin Crouch (2000), the impoverished state of affairs in UK politics should be attributed, to a considerable extent, to the use of communication techniques largely drawn from the mass persuasion techniques of the advertising industry. Last but not least, in Section 6.1.6 we will see that the Straussian mindset can distort the logical analysis of scientific problems, leading to potentially hazardous situations. For example, if the exposure attribute X_p causes a population health effect Z_p, even if the probability of an intentionally false exposure assessment $P_{KB}[X_p = \chi_p]$ is very small, the probability $P_{KB'}[Z_p = \zeta_p]$ of the erroneous health effect resulting from the propagation of the original false statement can be very large, thus leading to the wrong conclusions about the population health situation. This error propagation does not really bother postmodernists who do not attempt to refine their thoughts about what is right or wrong, true or false, good or evil (McCallum, 1996).

Apparently, shadow epistemology's rule of not volunteering the truth to the public is high in the agenda of German politics too. During the 2009 swine flu crisis, the politicians arranged for themselves to get a better and safer flu vaccine than ordinary Germans. In this way, politicians effectively created what *Spiegel*[46] called a "two-class medical system in twenty-first century Europe." When the plan was uncovered, it caused an uproar in the country: "The separate vaccines amount to big risk for the people, little risk for the government. This type of second-class medicine cannot be allowed to exist in a democracy."[47] Wolf-Dieter Ludwig, chairman of the Drug

[46] *SpiegelOnline*, Oct 19, 2009: "Second-Class Medicine: Germans unhappy with alternative swine flu vaccine for politicians."

[47] Ibid.

Commission of the German Medical Association, called the planned vaccination campaign "a scandal." "The fact that politicians and top civil servants in ministries will be vaccinated with a vaccine other than the people is a terrible sign," according to the head of the Institute for Hygiene and Public Health at the University of Bonn, Martin Exner. In essence, the above is an example of what happens when the shadow epistemology is the pseudo-theory of knowledge that underlies the solution of a real-world problem (in this case, protection against the H1N1 virus): very different solutions (vaccine qualities) are chosen for different social classes (privileged elites vs. common people). The German flu vaccine scandal is merely one in an increasing series of incidents worldwide demonstrating the real life and death difference between "being a ruling elite member" versus "being an ordinary citizen." *Φωνή βοώντος εν τη ερήμω*:[48] like the prophet's "voice of one crying in the wilderness," the isolated voices of a Martin Exner and a Wolf-Dieter Ludwig will have little or no effect, as long as common people allow themselves to fall victims of the shadow epistemology and be brainwashed by the power holders.

1.4.4 The Ultimate Blackmail

In the financial sector, shadow epistemology has emerged as a prime tool of corporatism with the sole purpose to justify on pseudosociopolitical grounds the brutal tactics, shameless lies, and immoral policies of the powers that be in their effort to protect established interests. History shows that when the big financial institutions make profits, they get the benefits; when they are hurt, the Federal Reserve Bank makes sure that the people pay the huge costs. According to *The New York Times*, top executives at nine U.S. banks paid themselves over $20 billion in bonuses just weeks after taxpayers bailed them out to the tune of $700 billion (Story and Dash 2009). Ironically, corporatism has been also called welfare for the ruling elites – socializing losses and privatizing gains. Whatever the name may be, it serves as a reminder that some things basically never change (see Taleb 2008a, for an insightful yet humorous analysis of the phenomenon). Ironically, corporatism has been also called welfare for the ruling elites – socializing losses and privatizing gains. Whatever the name may be, it serves as a reminder that some things basically never change. Carl Hausman (2000) reveals how the industry of deception is growing at an alarming rate in business and politics. According to Harold Meyerson (2009: A19), the financial sector defended its huge profit, "by arguing that it had created many innovative financial products – the very financial products that managed to downturn into Great Recession." However, Meyerson notices, "the former Fed chief Paul Volcker said that he has 'found very little evidence that vast amounts of innovation in financial markets in recent years have had a visible effect on the productivity of the economy.' He went on to say: 'All I know is that the economy was rising very nicely in the 1950s and 1960s without all of these

[48] *John* **1**:23.

innovations'." In other words, Volcker's statement is yet another testimony of financial markets' "deception in advertising." Indeed, there is no much more in the markets' philosophy than this motto represents. Yet (Rushkoff, 2010: xv), "as our corporations crumble, taking our jobs with them, we bail them out to preserve our prospects for employment – knowing full well that their business models are unsustainable ... We know of no other way. Having for too long outsourced our own savings and investing to Wall Street, we are clueless about how to invest in the real-world of people and things."

Worth-mentioning are Slavoj Zizek's thoughts about the massive bailout money that corporatism demanded and received by the government during the 2008 financial meltdown. Zizek (2009: 18) wondered what kind of a society rendered such a corporate *blackmail* possible. Before leaving this section I would like to add that, once upon a time in business affairs people used to get what they deserved (on the basis of their hard work, professional abilities, etc.); later they realized that they will get what they could negotiate; today people usually get what they are able to blackmail. This is the legacy of corporatism's obsession with the "winner takes all" and, at the same time, another definite sign of moral decadence.

1.4.5 Papa Stalin's Motto and the Beggar's Waltz

In scientific research and development, the shadow epistemology introduces private ways of communication between members of the ruling elites that largely exclude the views of the vast majority of scientists (about noteworthy problems, their possible solutions, and other matters of scientific relevance). In most cases, the emphasis of shadow epistemology is on appearances and celebrity culture ("star" faculty, the system that promotes them, etc.; Section 8.4.4), rather than substance and meritocracy. Consequently, shadow epistemology creates an environment of low intellectual standards, unable to appreciate quality, and especially prone to deception and manipulation. This is the environment sarcastically described in Ernest Hemingway's quote: "If you have a success you have it for the wrong reasons. If you become popular it is always because of the worst aspects of your work."

Decision centers concerning scientific priorities and funding allocation (in E.U. and U.S.A. alike) are inhabited solely by tribes loyal to the clerkdom, and have almost ceased to engage in any direct sense with individual scientists. Instead, all kinds of schemes are used (fake surveys, carefully controlled focus groups and committees) that supposedly provide a means of communication between the decision-makers and the larger population of scientists. The objective of such schemes is to give the impression that individual researchers participate in the decision process – by voting in polls or expressing their views in surveys – but the real purpose these schemes serve is to legitimize what has already been decided by the power holders. In this respect, the shadow epistemology of the scientific establishment seems to embrace Papa Stalin's motto: "Those who cast the votes decide nothing. Those who count the votes decide everything."[49] Among many other observers of science affairs, João Medeiros (2007: 20) brings to the public's attention the disturbing fact that careerists may suppress via the peer-review process the appearance and dissemination of problem–solutions and research findings that refute their results, thus condemning their scientific field to perpetuate false dogmas. Advocates of the prevailing worldview have been observed to band together in opposition against alternative ideas with perhaps more antagonism than one might expect from objective scientific debate. And the opposition is not limited to publication of new science; jobs and grants are also more easily allocated to those affiliated with the scientific party in power (Section 8.4). As a matter of fact, *οι παροικούντες την Ιερουσαλήμ*[50] (as Luke calls those "in the know") are aware of numerous tragicomic relationships developed between researchers and funding agency administrators. Characteristic is the case of the NSF[51] administrator who was guaranteeing research funding to faculty under the condition that they admit members of his family in their university's graduate programs. Another humiliating case was that of the senior professor who was dancing the beggar's waltz in front of the EPA administrator declaring that, "I will do what you want me to do, let me be your slave."[52] Neil Pearce (1996, 2007) talks about the "rise of corporate epidemiology" that has "seriously jeopardized the public's health... Many prominent epidemiologists regularly accept funding from industry either to conduct research, or more commonly to criticize research conducted by their colleagues. In some cases, this has gone so far as assisting industry attempts to block the publication of important findings." He also mentions "episodes of industry cover-up or denial of deadly hazards, as in the Johns-Manville asbestos episode," and "the attempts to suppress the occupational hazards of brown lung disease" (see, also, Brodeur, 1985; and Levenstein, 1991).

It is infinitely saddening to think of the damage that the clerkdom's higher education model (Section 1.5) has caused to the minds and souls of what used to be honorable members of the society. No doubt, establishing a system that can harm the credibility and integrity of others is a basic strategy of the clerkdom in its effort to achieve its goals. This strategy has been routinely used, e.g., in the various deals of corporatism with politicians, governments, the media, the public, and even its own employees, when necessary. There was nothing to make one believe that the clerkdom would not apply the same strategy in higher education matters. In fact, given the social unskillfulness and political ineptness of many academics (partially brought on by their over-reliance on professional expertise, and by allowing themselves to be enclosed in and suffocated by the academic microcosm), this was a rather easy matter. What is difficult to understand is why the various elites of the sociopolitical system that praised

[49] As many readers probably noticed, the Papa Stalin's motto could apply equally well to the 2000 U.S. presidential elections and the controversy over the electoral votes of the state of Florida.

[50] *Luke* **24**:18.

[51] National Science Foundation

[52] In this case, one is reminded of the promise made publicly by a candidate during his 1996 U.S. Presidential campaign: "If you want me to be Ronald Reagan, I'll be Ronald Reagan."

corporatism's involvement in higher education did not think about the consequences of supporting a system whose prime characteristics are ultimate greed, domination, and exploitation. Naturally, the real victims are those individuals who say the Cavafian *Big No* (Section 2.3.1). As a matter of principle, it is difficult for many honest scientists and decent politicians alike to dance beggar's waltz. Many brilliant scientists and visionary politicians have disappeared from the scene for this reason alone.

In light of the discussion above, there is no doubt that the shadow epistemology has caused major damage not only to the social and financial sectors, but to the educational and research system as well (as we shall see in Section 1.5, this includes the conception and organization of today's university, its ideals, and ultimate goals). Jeremiads were right. For some time now, the university no longer participates in the historical project of culture (developing, affirming, and inculcating national culture). This project was the legacy of the Enlightenment, but means nothing to the modern philistines. In his insightful treatise on a very difficult and necessarily emotional topic, *University in Ruins*, Bill Readings (1996) observes that the university either functions independently by analogy with a transnational corporation (U.S.A.), or is tied to the transnational instances of the government (E.U.). The fact that the current academic environment is dominated by a flawed mindset has severe consequences on the kind of education available to students, and its life-long effect on the society at large.

1.4.6 Εάλω η Πόλις![53]

Intellectually, there is little that is more draining than shadow epistemology with its dried up rituals, its closed worlds, and its thinking without thinking. By legitimizing the actions of organized groups of influencers and networks of interlocking players who work behind the scenes and operate in and around global gray zones, shadow epistemology rapidly transforms societies worldwide. It has become clear that shadow epistemology promotes ethically challenged methods, and an egocentric thinking that manifests a deep terror of candour and meritocracy. As such, it presents a self-serving perspective that shows a preference for systemic deceit, routine manipulation of truth, and widespread corruption. While some people call this perspective pragmatic, it is probably just as accurate to call it barbaric.

Despite the widespread societal corruption it has generated, and the huge damage to human values and principles it has caused, shadow epistemology continues to be the dominant pseudo-theory of knowledge of the corporatism era worldwide. Many sober observers of human history wonder if the time has come for people to cease living in a virtual reality, and for the sake of future generations find the courage to end the present act of the human drama with the painful yet cathartic cry, *Εάλω η Πόλις!*

[53] "The City has fallen "was the desperate cry heard among Constantinoples' ruins signaling the fall of the city to the Ottomans (May 29, 1453), after a long period of hopeless sacrifice and suffering. This cry came to symbolize the end of an era and the beginning of a new one that eventually led to the Enlightenment.

1.5 The Unholy Alliance of Corporatism and Postmodernism in Higher Education

One of the most interesting features of the discussion so far is that modern philistines are not found only in the domains of government, business, and politics. They also abound in academic and research institutions, where they conveniently assume various chameleonic forms and shapes in order to promote their dubious agenda.

1.5.1 The Postmodern Corporatism University

A unique and rather strange phenomenon in higher education is the *unholy alliance* between financial corporatism and radical postmodernism. At first sight, there seems to exist all the world of difference between an intellectual, pluralistic, anti-establishment, and ironic doctrine (postmodernism), and a business-driven, anti-intellectual, control-seeking, monolithic, and voracious bureaucracy (corporatism). Yet, despite their differences, what brought these two unlikely allies together was their deep anti-Enlightenment convictions, and common hatred (for their own different reasons) of classical education, cultural literacy, traditional human values, and historical heritage. Enlightenment values like truth, right, and morality have no validity in radical postmodernism and financial corporatism – there is a notable lack of existential meaning in both. During the last few decades, Enlightenment paradigms of knowledge have been under attack from a wide array of sources – postmodern, postcolonial, feminist, flexian, and neoconservative. By assaulting traditional values in higher education, postmodern nihilism weakens students' minds so that they are unable to pose serious resistance to corporatism when it tries to reduce them into consuming units. If there is no right and wrong, truth and lie, cynicism prevails and people lack motivation to oppose corporatism's plans. If postmodernism has convinced people that all opinions carry the same weight (so that, e.g., pop stars have the same impact on public opinion concerning major environmental issues as Nobel Prize experts), why should not corporatism take advantage of the situation to promote its interests? Both radical postmodernism and greedy corporatism sought to weaken the traditional influence of the scholar on campus and the society at large. Often, more power is given to administrators with flexible consciousness. For example, it should be credited to the spirit of the era that the NSF administrator (Section 1.4.5) continued disrespecting any form of justice, ethics and meritocracy until his retirement: a man of his (decadent) time, no doubt. Corporatism's deeply entrenched antipathy against academic scholars and intellectuals is well known, but the situation does not seem to be any better with postmodernism's attitude towards them. The well-known postmodernist Jean-Francois Lyotard, e.g., suggested that the professor is "no more competent than memory bank networks in transmitting established knowledge" (Furedi, 2004: 7). In sum, the two "allies" have more in common than previously thought.

This unholy alliance took advantage of the prolonged phase of Decadence of western societies, and its end result was the unconditional dominance of a mixed model of ill-conceived deconstruction and reckless and shortsighted utilitarianism that gave rise to a paradoxical creation that can be characterized as the *postmodern corporatism university* (*PCU*). Representing the power holders in the business and political sectors, modern philistines were able to manipulate disillusioned academics and to instrumentalize careerists and opportunists in higher education. It is difficult to avoid the impression that since the 1980s the unholy alliance masterfully coordinated (*a*) the sharp decline in funding (federal and state) for higher education orchestrated by corporatism, in its effort to damage the image of traditional university in the eyes of the public,[54] with (*b*) the eruption of the inexcusable "cultural wars," when all too quickly universities turned away from the "spirit of the Enlightenment" to follow some fashionable trends conveyed by postmodern ironies. During the same period, honest faculty and the student body probably lacked an adequate understanding of the carefully crafted attack and its far-reaching implications. And so the drama of higher education began unfolding during the last few decades.

To emphasize the strong connection between the two, Fredric Jameson (1991) called postmodernism the "cultural logic of late capitalism." For Jameson the postmodern merging of all discourse into an undifferentiated whole was the result of the colonization of the cultural sphere by a newly organized corporate capitalism. In his discussion of the influence of postmodernism on large corporations, Terry Eagleton (2003) argued that by 1990 postmodern culture had become indistinguishable from corporate capitalism.[55] In U.S.A., an early corporatism model of education was implemented in the 1930s by none other than Woodrow Wilson. A more recent description of the university in corporate administration terms was provided in the report that Alfonso Borrero Cabal (1993) prepared for UNESCO. The report is essentially a parody of analogical thinking, involving the sequence process of business management on the one side of the analogy, and the running of the university on the other side. The final product is based on an insufficient understanding of either sides of the analogy, and a poor conception of the meaning of the term "analogy" itself, as is thoroughly demonstrated in Bill Readings' analysis of Borrero Cabal's report (Readings 1996). Nevertheless, Borrero's is the kind of simplistic approach to a serious subject that has an irresistible effect on the weak mind. Corporatism's plans targeting higher education were aggressively promoted in a variety of forums, such as the 1998 World Conference on Higher Education in Paris (CAUT 1998): "For the powerful forces seeking to control postsecondary

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[54] Corporatism's crocodile tears for the public funds "wasted" in higher education will live in infamy.

[55] The implementation of postmodern corporatism ideas in the real-world is sometimes profoundly opportunistic. For example, while Greek tourism (the country's most profitable industry) is based on the promotion of the great achievements of the Ancients, for years the country's postmodern politicians had abolished the teaching of ancient Greek in schools. Hypocrisy at its worst: actively opposing tradition and at the same time taking advantage of its worldwide fame for financial gain.

education, led by the World Bank and its allies, the enemy are university teachers around the world; and war has been declared. The battle cry is that higher education 'must proceed to the most radical change and renewal it has ever been required to undertake.' And that means radically changing the 'traditional' or 'classical' or 'research based' university and its personnel to meet the ravenous needs of the knowledge-based global economy…[World Bank's] reform agenda demands that decision making power in higher education should be wrested away from governments and institutions and vested in the clients (students) and customers (business and industry) and the public." The reader may want to keep in mind that many of the bankers who in the 1990s sought to reform higher education belong to the same species that a few decades earlier Franklin D. Roosevelt called "banksters." And it is probably the same species of bankers that later earned the characterization *kleptocratic*.[56] According to Michael Hudson (2008: 1–2), "a kleptocratic class has taken over the [world] economy to replace industrial capitalism," and the World Bank invaded "post-Soviet economies … pressing free-market giveaways to create national kleptocracies." Undisturbed by the financial crises they have caused, and having been bailed out with taxpayers money, the "banksters" continued to amass huge profits by inflicting serious damages to the world economy in terms of credit default swaps and other dubious financial tools (Story et al. 2010). This being the case with the corporate "banksters," one legitimately wonders what possibly they have in common with higher education institutes (seeking truth and moral values, and aiming at character building), which ironically the "banksters" sought to reform. It was like having left the wolf to guard the sheep.

The unholy alliance's plan for a modern university eventually took the form of the PCU model of today's higher education. This model fiercely fought to turn the university into a mixture of blatantly utilitarian and ahistoric entities, and make it subject to the profit imperative of the global markets. To speak plainly, the goal is no more to inculcate the exercise of critical judgment and creative thought, but rather to manage data and search for quick answers (quick and dirty might be nearer the mark) so that there is enough time for the student to be involved in pleasant activities of all sorts, primarily entertainment and consumption of goods and images ("buy in order to be"). Minimum effort is the golden standard of the PCU model of higher education, whereas the vulgarism of market-promoted consumerism dominates the campus culture. As Marc Edmundson (2004: 17–20) acutely observes, "Colleges don't have admissions offices anymore, they have marketing departments… Before students arrive, universities ply them with luscious ads, guaranteeing them a cross between summer camp and lotusland. When they get to campus, flattery, entertainment, and pre-professional training are theirs … greeting great works of mind and heart as consumer goods. They came looking for what they'd had in the past, *Total Entertainment All the Time*, and the university at large did all it could to maintain the flow." As a matter

[56] Having its origins to the Greek words κλέπτης (thief) and κρατώ (rule), "kleptocratic" denotes corruption seeking to extend the personal wealth and political power of a ruling class.

of fact, for the postmodernist Alan S.K. Kwan (2005), "There is nothing intrinsically wrong with entertaining education." Wrong? But postmodernism gives no standard even to say this. Apparently, PCU's goal is to prepare the citizens of Aldous Huxley's *Brave New World*, i.e. citizens who are oppressed by their addiction to amusement (Huxley 1998). Bernard Schweizer (2009) is concerned that the ahistoric mindset of radical postmodernism (characterized by its massive suspicion of privileged, specifically western, masculine, white values) has produced students whose reading comprehension skills are flat, anemic, and literal rather than deep, rich, and associative. Postmodern deconstruction is hostile to major intellectual traditions and human achievements of the past. Accordingly, in the PCU environment, a student is more likely to know everything about ephemeral pop-culture celebrities than about Plato, Homer, Galileo Galilei, Fyodor Dostoevsky, Ernest Hemingway, or Virginia Wolf. Radical deconstruction is against critical thinking and the search for deeper meaning in one's actions: if all choices are considered equally important, there is no reason to implement critical thinking in making a meaningful choice or deriving a sound problem–solution. Since it favors the disappearance of significations and the almost complete evanescence of values, radical deconstruction can be a serious obstacle to good education and active citizenship. Talking about the damaging effects of deconstruction in U.C. Berkeley, the Pulitzer Prize winning author Chris Hedges writes in a rather ironic tone that (Hedges 2009: 93), "U.C. adores the slogan 'Excellence Through Diversity,' but it doesn't mention multiculturalism's silent partner – the fragmentation of student society into little markets, segmenting the powerful sea of students into diverse but disarmed droplets."

An important factor that contributed to the state university's decline as a center of higher education and character building is that the tasks assigned to publicly funded universities are far too many and sometimes even unrealistic, given the general resource scarcity. In addition to its traditional duties, the university is expected to provide many different services outside the campus (local societies, organizations, government agencies, etc.). According to Sheldon Rothblatt (2006: 47), "Their [universities'] integration with government, society and industry is so extensive that they often appear to be just another of society's institutions providing a realm of services and offerings that change according to outside funding. They are creatures of government 'policy'." In view of the above considerations, it is not surprising that the PCU mindset has caused a highly consequential division between (predominantly state) schools and universities that offer low-level education (training may be nearer the mark) to the many unprivileged students coming from the low-income section of the society; and the (predominantly private) schools and universities that offer all advantages of high-level education to the privileged few students coming from the wealthy section of the society. In fact, the educational achievement of American people is directly correlated with their income, whereas, as a United Nations report observed, higher education in the land of the free is remarkably illusive (Capra 2009: 75). Far from benefiting the unprivileged students coming from the low and middle classes of the society, with its abolishment of sound education (in terms of advanced science courses and cultural literacy), the PCU model has made it a possession of the privileged students coming from the upper echelons of society. It is no wonder that *social mobility* is lessened significantly, and the gap between the many poor and the few rich people is continuously widening during the era of PCU's domination in higher education.

1.5.2 The Lost Possibility of Experiencing Themselves

Radical postmodernism teaches the students that since there is no one truth, there is essentially no error. Accordingly, students are encouraged to make what often turn out to be arbitrary and meaningless choices. Students can choose, e.g., to devote their time in total entertainment and endless consumption all the time, which is in line with the corporatism subculture. As this was not enough, since one's moral values are based on the meaning of one's life and actions, a meaningless life is a life void of such values. As strong a statement as it may sound, people's possibility of *experiencing themselves* is effectively cut off at an early age by the organized subculture. The PCU world is free, perhaps, but empty, nevertheless.

To call a spade a spade, although there is plenty in a typical PCU curriculum that a student can find entertaining, there is usually little in the curriculum that the student can find intellectually challenging or inspiring. Most PCU administrators are too intent on establishing a corporate atmosphere, both to facilitate their control and aggrandize their own positions. While they spend considerable time massaging numbers in order to attract students (Hausman 2000), they do not even consider the possibility that the university ought to provide young students the skills that can enable their search for identity, meaning and purpose in life, and allow them to build and preserve a healthy society. In many campuses, resources are increasingly depleted, morale shattered, all sense of clear direction and vision of the future abandoned. Students are educated with empty slogans to the point that one is amazed by the pompous and vulgar illiteracy many of them develop. By now, there is ample evidence that for the university's failure in the aforementioned important respects, many unsuspecting students have paid and will continue to pay a high price during their professional and private lives. The unanswered challenges of the current phase of Decadence we are in worsen things considerably for the young students. The PCU model is completely unable to prepare students for the most critical features of life in the twenty-first century: the largely unknown but potentially catastrophic consequences of the anticipated slowing down of material growth and prosperity worldwide (both measured in terms of consumption indexes) as a result of economic globalization, international competition for vital yet diminishing resources, climate changes, and the like.

Arguably, many graduate programs of research universities are built on the basic premise that *technoscience* must meet with financial investment. The production of ideas aiming to attract the interest of venture capitalists and entrepreneurs (which varies from a new medicine that treats a disease to a shining but useless gadget that excites the imagination of unsuspecting consumers) is part of the operation of what "is the most ruthlessly instrumental sector of late modern capitalism and late modern technoscience" (Shapin 2008: 270). Many talented graduates are unaware of the real possibility that corporate interests recruit them into an environment of which they will always be the "outsiders," and which considers them expendable when cease to be useful to the interests they originally were enlisted to serve. There is no doubt that an adequately designed "technoscience–business" collaboration with a serious consideration of human values and intellectual standards can create products that benefit humanity. On the other hand, based on the available evidence, two major practical concerns have emerged about this collaboration: (*a*) when a substantial investment has been made on the development of a specific product, it is not unusual that every effort is also made to eliminate competing efforts,[57] thus creating serious obstacles to scientific progress; and (*b*) in many cases the priority of the operation is not the urgent need to improve the quality of life, but to produce financial gains (so-called quick money) for the investors, even at the cost of basic human values. These concerns are of great consequence for the ethos of the PCU model and the society at large.

1.5.3 What St. Augustine and Prophet Muhammad had in Common

An issue where the unholy alliance of self-serving corporatism and radical post-modernism is at its closest is their common dislike of well-rounded scholarship. This includes their shared position against book reading and other means that could improve cultural literacy, promote traditional values, and provoke critical thinking. In many cases, students are discouraged to read books that will not have what the PCU mindset considers an immediate "productive" result (and this includes classic readings of the past that have proven their invaluable contribution to Man's search for meaning and purpose in life). Rick Shenkman (2008: 29) is then justifiably amazed when he discovers that, according to a large array of surveys (including the U.S. Census), "this generation is less well read than any other since statistics began to be kept."

PCU's attitude against teaching students how to seriously read and thoroughly research the literature can have very serious consequences for them. One of the consequences is that this attitude could undoubtedly legitimize plagiarism. Remarkable although not atypical is the incident of the PCU science professor who, when confronted with the fact that his supposedly "novel" research results were already well known and could be found in science books, the good professor responded: "I don't read books anymore." In postmodern terms, if the good professor does not read books, it is like the books do not exist. In which case, one may recall Einstein's famous response: "Are you saying that the moon does not exist if you do not look at it?"

[57] There are many cases when an investor lobbies the government not to fund competing research proposals, or a big corporation buys out a small company in order to destroy innovation that could threaten the corporation's complete control of the market.

In another remarkable case, Mark Bauerlein quotes another distinguished PCU professor who showed so little regard for her field to the point of arguing that (Bauerlein 2008: 60), “I don’t care if everybody stops reading literature… it’s my bread and butter, but cultures change.” The sociologist Frank Furedi mentions a remarkable study according to which, “In many cases, students could spend an entire year at university without reading a whole book.” He then describes his encounter with a senior university manager who “was angry about my arrogant assumption that books should have a privileged status in higher education… As far as he was concerned, the book has become an optional extra resource for the present-day undergraduate” (Furedi 2004: 1–2). Also, in his review of a book critical of corporatism, Bill Mayer added another political dimension to the debate: “Luckily for Congress, the White House, and Corporate America, no one reads anymore, because if people discover this book, America will become a very different place.”

Indeed, as far as the above PCU educators and administrators are concerned, it is sufficient that the students just learn to quickly search the Internet, where they can find all the information they need. Surely, there are many educated arguments against the above perspective (including student plagiarism),[58] but we will limit ourselves to a very pragmatic one, and point out its fatal consequences. What escapes the attention of the philistines of the PCU system is that, as every good librarian knows, the idea that everything is available on the Internet is a serious misperception. What is even worse is that this misperception can be proven fatal. For example, in a widely publicized case (Bor and Pelton 2001), a Johns Hopkins medical researcher limited his search concerning the possible adverse effects of the drug Hexamethonium on Internet resources, including PubMed (which is searchable only back to 1960). In this way, he failed to uncover published research in the 1950s (with citations in subsequent publications) that warned of lung damage associated with the specific drug. The result was the tragic death of a healthy 24-year-old woman in an asthma experiment. Dr. Frederick Wolff, a professor emeritus at the George Washington School of Medicine, told reporters that, “What happened is not just an indictment of one researcher, but of a system in which people don’t bother to research the literature anymore.” Dr. Wolff’s statement offers yet another powerful demonstration of the potentially fatal consequences of the PCU educational system, and the huge responsibilities of those who have aggressively supported PCU during the last few decades. The above deficiencies of the educational system and their far-reaching consequences are the product of an arrogant and unregulated PCU system, in which campus

[58] A study by The Center for Academic Integrity found that almost 80% of college students admit to cheating at least once; and a poll conducted by US News and World Reports found that 90% of students believe that cheaters are either never caught or have never been appropriately disciplined. What is worst, too few universities are willing to back up their professors when they catch students cheating, according to academic observers. The schools are simply not willing to expend the effort required to get to the bottom of cheating cases, as stated by The National Center for Policy Analysis (http://www.plagiarism.org).

bureaucrats have become more influential in educational matters than scholars. These bureaucrats, often playing the control game to mask feelings of inferiority, can even cause serious problems to the faculty's conscientious effort to perform their duties, with the students paying the ultimate price – their education.[59] This is all part of PCU's ongoing war against intellectuals and scholars on campus. The PCU system has every reason to marginalize scholars, because scholars constitute the most serious obstacle to clerkdom's prime goal to misdirect public's attention from the dirty work that is going on behind the scenes and in the shadows. It may be of some consolation to the noblemen and noblewomen of thought that more than 2,000 years ago the Muslim religious leader, Prophet Muhammad, had this to say about scholarship (De Bono 2009: 171): "The ink of a scholar is more holy than the blood of a martyr." Similar is the message of St. Augustine's doctrine, *intellectum valde amat*, encouraging his Christian followers to love the intellectuals. Talking about a clear, across religions condemnation of PCU's anti-intellectualism.

Abyssus abyssum invocat: Because one misstep leads to another, the "minimum effort" golden PCU standard finds a public advocate in Richard Cohen's kind of populist journalism. Cohen's bleeding heart goes out to a Los Angeles high-school student who failed algebra six times in six semesters (a case probably worth of the Guinness book of records). In a column published in *The Washington Post*, Cohen (2006) attacked high-school systems that required "students to pass a year of algebra and a year of geometry . . . it is the sort of vaunted education reform that is supposed to close the science and math gap and make the U.S. more competitive. All it seems to do, though, is ruin the lives of countless kids." In a sense, the message here is that, in addition to drinking and smoking, another bad habit that could possibly ruin young people's lives is mathematical education. One is surprised why Cohen does not go one step further and suggest that the government ought to issue a law that requires publishers of mathematics books to add the appropriate warning label, just as it is done with the products of tobacco industry. To his credit, Cohen admits his own mathematical illiteracy: "I can do my basic arithmetic all right (although not percentages) but I flunked algebra (once), barely passed it the second time. . . somehow passed geometry and resolved that I would never go near math again." Following Cohen's own radically postmodern reasoning, one may legitimate wonder why schools should require students to learn history, geography, or any other subject? After all, Cohen acknowledges that many students have the same negative attitude toward these subjects as others have toward algebra. According to him, all one needs is some typing skills: "I let others go on to intermediate algebra and trigonometry while I busied myself learning how to type. . . Typing: Best class I ever took." Admittedly, one does not expect this sort of journalism that aims to entertain a certain group of readers, to also address their substantive needs, or to be seriously concerned about young people's future in an increasing competitive world. The world being what it is

[59] Insane as it may sound, there are cases where campus administrators forbid faculty to use funds to purchase books, arbitrarily characterizing their contents as irrelevant to the educational and research plans of the faculty.

today, one thing that this kind of journalism could really achieve, perhaps unintentionally, is to serve the dark side of the system: flatter the youth and promote illiteracy, with the ultimate goal of creating cheap labor.

1.5.4 Politicians, the Professoriat, and Einstein's Mule

Any academic policy that leads to the dramatic lowering of the educational standards offers the perfect excuse career politicians need in order to pursue their goal of reducing, or even eliminating, state funding at no real political cost. No doubt, the PCU model of higher education serves perfectly this political objective. Amusing yet illustrative of the prevailing perspective among a number of politicians is the case made by the South Carolina Rep. Harry Stille concerning the reluctance of key State legislators to give University of South Carolina more financial support (Monk 2000):

> Not until they increase the quality of their student body. Even Einstein can't teach a mule!

Under its picturesque surface, Stille's comment sends a clear warning to all concerned. At the other end of the spectrum, one finds politicians and all sorts of activists who request that the university reformulate its structure and revise its mission in order to respond to demands of the local societies on an almost daily basis. All these demands can easily divert university from its prime huge task as society's place of higher education, and even put it at jeopardy. In addition, as Thorsten Nybom (2008) points out, when it comes to knowledge, local communities very rarely actually know what they will really need in, say 15 years time, not to mention in a generation.

This being the case, the first step in handling any kind of challenge is to gain the ability to face it. Unfortunately, in many campuses the proletarianized professoriat has long lost the kind of ability and flexibility required to confront the problem. There exist a number of reasons for this sad state of affairs. One of the main reasons is that the corporate organization of universities imposes a high level of control not only of the financial flows but of professoriat's behavior as well. Many faculty members (although highly competent in their fields of expertise) often lack the sophisticated understanding of the social context needed to fully absorb the extent to which they are subject to manipulation by the PCU unholy alliance. Other faculty members chose to live inside their microworld, where they can enjoy a cocktail of apathy, delusion, and deceptive sense of exceptionalism. The same proletarianized professoriat, either hypocritically claims that "nothing is wrong with the system" or pretends to be innocent bystander to the drama of higher education laid out before its own eyes. It is amazing, and also infinitely sad, to watch faculty exhibit a disturbing apathy in front of the catastrophic course of events that is left to a small number of courageous noblemen and noblewomen to confront. What is worse, far too many faculty members demonstrate obsequious acquiescence to every wish of the campus clerkdom. They give up their dignity and submit unresistingly to the humili ation imposed on them by the PCU system. How can one expect these educators to teach freedom of thought and human values to their students, or to satisfy their needs for comprehension, insight, and inspiration? It is also of considerable socio-anthropological interest that for so long the parents of the students are unwilling to face the real facts, even if some of these facts could give them a bad case of indigestion. Sometimes, the saddest cases are faculty members turn in to administrators. These cases bring to mind Franz Kafka's story in which the hero, Gregor Samsa, is metamorphosed into a bug (Kafka 1915). For many of these administrators, the main motivation is the urge for power and control at any cost, which is why when they are engaged in an intellectual debate they tumble into confusion and they appear to others as what Tom Paine used to call "laughable, pathetic creatures" (Keane 1995: 121). Nevertheless, they consciously serve the PCU system, and share responsibility for the sad state of affairs in higher education. As a result of the above, an academic environment is often established in which talented young faculty continue to wallow in perpetual mediocrity and nonsensical activities of all sorts, since real achievement and substantive success are neither encouraged nor rewarded. Without any real opposition, PCU's political agenda has for many years orchestrated the drama of higher education.

1.5.5 Citizens with Market Value Versus Social Capital

As has already been emphasized, the public ought to realize that in the PCU system, the campus philistines have much more power and influence on matters adhered to university's mission and everyday functioning than the scholars. Free then of any intellectual regulation, the suffocating control exercised by the PCU model has many negative consequences. One of them is the serial production of citizens with market value rather than the creation of social capital. This essentially eliminates the possibility that the university prepares citizens-critical thinkers who could question the actions and policies of the ruling elites (political, financial, educational, etc.). Another consequence is the extinction of any heretic ideas, even the brightest ones, which could challenge the orthodoxy. Paralyzing logistics prevail that limit time devoted to thought-provoking teaching and creative project undertaking on campus. In the process, the PCU model corrupts the youth in ways never seen before. As noted earlier, the students are encouraged to view the campus as a place of "train-and-entertain" rather than a place of deep learning, introspection, and self-cultivation with long-term benefits. Advanced courses that can sharpen the mind, widen the knowledge horizons, develop creative problem-solving skills, and thus improve one's chances in a highly competitive job market are rarely offered in colleges due to lack of perceived eligible students. Furthermore, the PCU model encourages students to view all human relationships as "connections." These are murky connections that practice courtiership and mutual favoritism, and support mediocrity and injustice. As such, these connections are proliferating wherever there used to be human values and a good life environment. Many hard-working educators cannot forget the embarrassing motto of pseudo-pragmatism: "Those who can, do. Those who cannot, teach". This motto is, of course, one of the silliest things one can say, even measured by the low intellectual standards of corporatism. It also reminds people of the key distinction between education and training, the corporatism being strongly against the former and in favor of the latter. Indeed, from the very beginning the ultimate goal of the corporatism model was to completely change the university's focus from education to training. Lastly, it should not escape one's attention that this mindset, which favors blind action and keeps human mind thus subordinate, is the same mindset that characterized the pre-Enlightenment era and was expressly attacked in 1784 by Immanuel Kant (among many other great thinkers of the Enlightenment movement): "The officer say, 'Do not argue, drill;' the taxman says, 'Do not argue, pay;' the pastor says, 'Do not argue, believe!'" (Grayling, 2010: 158). One wonders whether corporatism tries to bring the world back to the Middle Ages.

1.5.6 Corporatism's Failure, and Its Effects on PCU

The system of financial corporatism is supposed to create jobs in the near future, but it ends up cheating the students out of long-term benefits. It can also induce huge damage to societies worldwide. The loss of millions of jobs, the destruction of the environment, the exhaustion of energy sources and the monomaniac focus on perpetual economic growth, all accompany the logic of corporatism. As recent history amply demonstrated, administrators and policymakers are more driven by their priority to serve the interests of big corporations than the needs of the people. For example, the unethical way corporatism treated the innocent victims of its greed that led to the 2008 worldwide financial meltdown will live in infamy. And it is a first-rate scandal that in a free market economy the government ended up doing the job of corporatism. Even *Economist* (a magazine that can hardly be accused of anti-corporatism propaganda) complained that, "Right now, government is one of America's few growth industries ... Federal government has spent some $700 billion to bail out the banks and another $787 billion to stimulate the economy. It has taken ownership share in parts of the car industry and forced other sectors to reorganize" (*Economist*, February 20–26, 2010: 25).

The situation has caused a huge outcry against vampire corporatism worldwide. People become aware of numerous (Huffington 2009) "stomach-turning revelations of corruption that have come to light" in a corporate world where "the new villains are playing with taxpayer money, trillions of it" at enormous human cost, causing tremendous pain, hardship, and fear to common citizens. This is how Galbraith (2009: 94) puts it: "Plainly, the intersection of economics and criminology remains a vital field for research going forward." According to Moisés Naím, greed, arrogance, and dishonesty together with intellectual confusion were the main characteristics of corporatism that led to the "unprecedented nature, scope and scale of the financial manipulation that took place" (Naím 2002). Indeed, the corporatism worldview can eliminate large numbers of jobs, destroy people's life-savings, throw families into misery and despair, and sacrifice countless innocent lives in unnecessary wars in order to increase its profits. In Europe the crisis is responsible for near-bankrupt state economies, booming unemployment, failing educational systems, large demonstrations and even riots. In the view of many analysts, in some states the riots indicate that a form of conflict may have emerged that is no longer easily manageable. Corporatism's increasing incompetence to deal with modern problems is demonstrated, *inter alia*, by the fact that it tries to solve twenty-first century problems using a twentieth century mindset. For example, it attempts to resolve the Internet copyright problem using bureaucratic means (forcing governments to issue draconian and often anti-freedom laws, censoring the electronic media, and even spying on people), which are sure to fail in the long run. Also, many corporations consider that the most valuable asset they own is their brand. But if a brand is based on people's perceptions of it (often by means of its logo or trademark), then Laura Biron and Dominic Scott (2010: 73) legitimately ask how can a corporation claim to own people's perceptions. In a certain respect, corporatism's attitude of possessiveness brings to mind regimes of the past. To make things worse, the facts show that the "corporate corruption of the U.S. political system is so pervasive and powerful," says Joel S. Hirschhorn (2009), that it comes as no surprise that "corporate corruption is a true bipartisan effort, perhaps the most bipartisan enterprise." It is tragicomical that despite their obvious incompetence, those in charge of the failed system are convinced that they are the *crème de la crème* of the society, and expect to be treated and rewarded accordingly (see, also, self-appointed unaccountability in Section 1.4.2).

In the middle of all this, the university must face the real criticism that it turns out to be a version of a transnational bureaucratic corporation that serves the flawed worldview described above. PCU's goal is to provoke students' lower needs (physiological comfort, material consumerism, etc.) and oppress higher needs (comprehension, insight, identity, and purpose). The former needs are connected with questions of *how*, whereas the latter needs are linked to questions of *why*. But questions of why are of utmost importance in an IPS context (Chapters 2 and 3), and an education that does not take this fact into consideration reduces considerably the students' professional prospects. Along these lines of flawed PCU thinking, academic policies give the impression that are more driven by a perverse priority to show their loyalty to the corporatism's worldview discussed above than to serve the human values and real educational needs of the future citizens. One must not forget that corporatism has lost no opportunity to make clear what it expects from the university, and this is not real education. As far as corporatism is concerned, the university ought to provide the kind of training that will allow its graduates (Edmundson 2004: 14–16) "to take up an abstract and unfelt relation to the world and its peoples," so that "they won't be able to squeeze forth the world's wealth without suffering debilitating pains of consciousness." This is the kind of training an investment banking recruiter had in mind when he emphasized that, "we like economics majors, because they're people who're willing to sacrifice their educations to the interest of their careers."

Remarkably, the PCU system seems to have failed miserably even in fields that it was least expected. One of them is the *technology-based economy*. All nations have recognized the crucial advantages of this kind of economy. During the twentieth century, America based its position as the number one economy in the world on its technological advances and innovations; Japan also used a variety of technology-based products to assure its position as a number two economy in the world. The same is the case of China, which already took the place of Japan as the number two economy. It is widely recognized that the three basic ingredients required to establish a technology-based economy are: (*a*) the discovery and promotion of extremely gifted people, (*b*) an education system based on high-level standards that are objectively valid worldwide,[60] and (*c*) the availability of resources for higher education, basic scientific research, and innovative development. It is quite remarkable that all three ingredients have been fiercely attacked by the policies of the unholy alliance of financial corporatism and radical postmodernism. Ingredient *a* suffered major blows from the postmodern policies of ill-conceived equality and sacrificing meritocracy on the altar of political correctness (all choices are equally important, disappearance of significations, and evanescence of values). The promotion of consumerism and the "train-and-entertain" doctrine of financial corporatism have crippled Ingredient *b*. The sharp decline of state and federal funding for education and research caused by corporatism and the "science wars" of radical postmodernism have caused a severe damage to Ingredient *c*. As this was not enough, corporations are awarded a disproportionally large amount of the U.S. government's research funding that used to go to universities and national research centers. For example, referring to the innovative research initiative of the National Reconnaisance Office (NRO), Lynn G. Gref notices that "the awards favor industry… In 2008, the results were that out of 27 awards industry received 24, universities received one, and government laboratories and FFRDC [federally funded research and development centers] received two" (Gref 2010: 118). This policy, *inter alia*, severely hurts the education of young Americans (much less funding is available for students, fewer resources exist for research and teaching improvements on campus, etc.), with no serious objections raised by the PCU system. As a result of the above and other similar developments, all indicators (such as the significant decrease in the number of new products and services originating in the U.S. per unit of GDP,[61] failure of salaries for scientists and engineers to keep pace, decreasing number of articles on science and engineering in peer-reviewed journals,[62] and the increasing number of American corporations investing in foreign research and development laboratories) show a definite decline in American technology (for a detailed and up-to-date analysis, see Gref (2010)).

[60] An education system that produces, e.g., great mathematicians has demonstrable worldwide characteristics.

[61] Gross Domestic Product.

[62] The NSF's science and engineering indicators show a greater than 30% reduction in the number of articles per billion of dollars of GDP during the 1995–2005 period.

1.5.7 Delenda est Carthago,[63] *and the Mythical Phoenix*

Who would have thought that the descendants of ancient barbarians are alive and active inside what were supposed to be centers for free thought, truth-seeking, and democratic process. Nevertheless, thanks to the efforts of a few distinguished individuals, more people are becoming aware of the deteriorating situation, although this does not necessarily mean that anything is going to change without a great effort by those who really care. One should not forget that the lethal embrace of society by the elites reaches its climax during a time of Decadence. The gravity of the matter has reached such a critical point that has got the attention of world-renowned authors and journalists. Among them, Lapham (2008b: 16–18) noticed that, "Students don't go to school to acquire the wisdom of Solomon... The tide of mediocrity flows into the classroom from the ocean that is the society at large ... the students herded into overcrowded classrooms where they major in the art of boredom and the science of diminished expectations, how better to accustom them to the design specs of a society geared to the blind and insatiable consumption of mediocrity in all its political declensions and commercial conjugations." In the same vein, Adrian Berry (2007: 124) emphasized that few of the Ph.D. students in biology can distinguish between speculation and theories; even fewer appreciate the need for revolutionary hypotheses, and fewer still can generate them. Also, Herbert Dingle remarked that, "It is my task to inquire how it has come about that a generation so amazingly proficient in the practice of science can be so amazingly impotent in the understanding of it" (Frank 2004: xiv). Friedman has repeatedly expressed his concerns about the American education system and the society at large. Reflecting on the serious damage imposed on the education system, Friedman quotes an IT architect who teaches computer science (Friedman 2007: 352): "It was disheartening to see the poor work ethic of many of my students. Of the students I taught over six semesters, I'd consider hiring two of them. The rest lacked the creativity, problem-solving abilities and passion for learning." The situation described in this quote is typical of many academic environments these days. What is also typical is the discouragement that any honest educator who wants to do something about the problem gets from many PCU administrators. Alas, as far as the education system is concerned, "the culture now is geared toward having fun" (Friedman 2007: 352). The time when academia was a place of passion for learning, self-cultivation, free thought, and democratic process seems to belong to the distant past. As Arianna Huffington (2009: xvii) puts it, "It's a battle between the *status quo* and the future, between the interests of the small but extremely powerful financial/lobbying establishment and the public interest." The clear danger is that too many universities have tied their fate to the priorities of corporatism that are increasingly directed away from what is right or good, which is why the university needs to urgently reinvent itself (Section 1.10). It is a high-stakes affair, one in which souls are won and lost.

[63] A phrase with which Cato the elder urged the Roman people to the destruction of Carthage.

To the enlightening quotes above, one could add a critical dimension of the problem that does not seem to receive sufficient attention in the PCU agenda: the future of a society is decided by its fundamental values (moral, aesthetical, and intellectual) than by policies in a narrow sense. It is common knowledge, e.g., that the best and the brightest in U.S.A. are expected to gravitate in the direction of money-making, even if this involves a twisted view of human principles and strong anti-intellectual and anti-aesthetical prejudices. For years, the insidious approach of the PCU system has produced many human beings with strong instincts for chronic consumption and debauchery, but with empty souls and numbed minds. Beings that are prepared to live in a world of nothingness and meaninglessness, which is hateful of intellectual abstractions such as Truth, Honor, and Trust. A world in which the same human beings abdicate their freedom of thought by reverting to the authority of others. Many scholars seem to be convinced that academia is doomed, whichever way one looks at it. This is so, according to their opinion, not only because of the tyranny of the *status quo*, but mainly due to the lack of serious opposition that characterizes the time of Decadence. Other scholars believe that we have reached a point of crisis, and it is about time to aggressively reject PCU's declaration "Delenda est Carthago" concerning classical education. The complete destruction of true knowledge and human values should not be allowed. Instead, like the mythical bird Phoenix, higher education must be reborn from its ashes. In this context, this book hopes to help readers realize what is at stake in higher education, and its severe consequences in real-world problem-solving.

1.6 On the Road to Damascus

In modern times, people often feel blessed to have at their disposal a huge amount of advanced knowledge about Nature. Nevertheless, despite its large quantity and occasional high quality, human knowledge encounters sharp limits, which means that we probably have a long distance to cover before we see the bright light *on the road to Damascus*.[64] Undoubtedly, the "visionary experience" we are all after will need to lead to efficient ways of overcoming certain rather serious limitations to reliable knowledge as currently conceived. Indeed, serious limits to knowledge emerge in connection with a number of issues. Some of the most talked-about among them are:

(a) The *paradox* that a human agent is at the same time observer and part of what one is trying to observe and comprehend. The agent lacks an *externalist* perspective of reality and is limited to an internalist perspective from within reality.

[64] A quote from the biblical story of Paul of Tarsus, who converted from Judaism to Christianity when he saw a bright light while traveling on the road to Damascus.

(b) The *uncertainty* associated with potentially inefficient cognitive structures (e.g., vision), cognitive technologies (e.g., microscope), and their interactions.
(c) The challenge of coordinating specialized disciplinary knowledge with the body of *multidisciplinary* core knowledge that transcends several disciplines.
(d) The difficulty to sustain any kind of constructive *criticism* under the utilitarian and anti-intellectual conditions that characterize that current social, political, and educational environments.

1.6.1 Beyond Complete Comprehension but Not Completely Beyond Comprehension

The Issues *a–d* briefly outlined above play a key role in real-world IPS, which is why it is worth investigating their essence and consequences in more detail.

1.6.1.1 The Paradoxical Role of Human Agent

Let us spare a few thoughts about the paradoxical role of the human agent (Issue *a*). Any cognitive activity includes the agent (observer), the external reality (observed), and the agent's perception of the external reality. In Fig. 1.3, the agent's perception includes visual and audio elements (the agent sees the teacher, students, and school, and also hears the sounds generated by them). The agent's perception is not always a clear-cut affair. Instead, it depends on a number of conditions: The effectiveness of her brain mechanisms and mind functions; eyesight and observational capabilities; background, ultimate presumptions, psychological state, and even prejudices; distance from the objects, as well as the environment's visibility state, and weather conditions. Depending on the occasional combination of the above elements, the

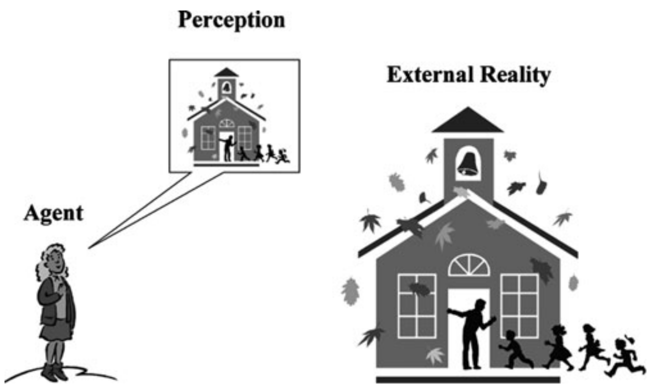

Fig. 1.3 Three components of a cognitive activity: agent, perception, and external reality

observing agent may perceive a happy or a concerned group of students, a pleasant or a tough teacher, etc.

In an important sense, the real problem is that the agent in Fig. 1.3 cannot move in a different dimension, from where she can observe the external reality and examine her perception of it, in order to obtain an objective assessment of how accurate a representation the latter is of the former. The matter brings to the fore substantive issues closely related to work in brain sciences (neurobiology, evolutionary psychology, and cognitive epistemology). How to use knowledge generated in these scientific fields in the context of modern IPS is of considerable importance to Epibraimatics.

1.6.1.2 Concerning Uncertainty

Issue *b* above is also extremely important in regards to human understanding and knowledge reliability, which makes uncertainty another central theme of this book. Multisourced uncertainty characterizes most in situ phenomena and, hence, needs to be taken seriously into consideration (Section 4.3). In many in situ problems, uncertainty is another way of saying that the natural system is too complex for an agent to describe fully – i.e. uncertainty is a measure of the agent's ignorance. In some other problems, uncertainty may be the result of the inherent features of the phenomenon or of the disturbances the agent causes when attempting to make a measurement or an observation (this is especially valid in the quantum world).

Being an important ingredient of human inquiry, uncertainty consideration has a long and rich history. Uncertainty about the essence of reality and Man's ability to know reality with confidence was present in early Greek philosophy (see discussion of Xenophanes' and Parmenides' teachings in Section 1.1.2). Interestingly, early Chinese philosophy was characterized by metaphysical and epistemological optimism that implied an approach to knowledge reliability that confidently used somehow looser standards (Metzger 1985–1987). Today, uncertainty is considered a critical element not only of natural sciences but of mathematics as well. For Paul Davis, "The popular image of mathematics as a collection of precise facts linked together by well-defined logical paths is revealed to be false. There is randomness and hence uncertainty in mathematics, just as there is in physics."

1.6.1.3 Problem Multidisciplinarity

Many theoretical developments and real-world problems are multidisciplinary. Accordingly, Issue *c* above is discussed rather extensively throughout the book. It concerns the obstacles that arise when different disciplines collaborate toward the solution of a multidisciplinary problem. For example, both atmospheric physics and toxicology are vital components of human exposure assessment. However, it is doubtful that an atmospheric physicist can read with profit the research work of a toxicologist, and vice versa. There are a number of sociological and anthropological reasons leading to this complex situation, which have been discussed extensively in the literature. The multidisciplinarity of an in situ problem can complicate things, since scientists from different disciplines may have different thinking styles. Further complications may arise from the fact that these scientists often use the same words in very different ways. Yet, despite initial obstacles and difficulties, it is the multidisciplinarity of a subject that makes it most exciting to study, and also proves to be its strength. Consider, for example, the increasing number of consciousness studies, which constitute a new and very important multidisciplinary subject (Blackmore 2004). Rooting out prior assumptions existing in separate disciplines is necessary if one is going to think clearly and productively about the consciousness problem.

Let us pause and reflect. Surely, there are serious obstacles to human knowledge and comprehension, and one must learn to live with them, and even initiate a dialogue with them, so to speak. Some of the potential obstacles were exposed in the discussion of the Issues *a-c* above, whereas others were not mentioned due to space limitation or the epistemic situation of the author. In any case, the same discussion also conveyed a message of hope: while reality may be beyond complete comprehension, by no means it is completely beyond comprehension.

1.6.2 Waiting for Godot

There is also the dark side of the resistance of certain career-oriented scientists to acknowledge the importance of disciplines other than their own, and participate in a joint effort to solve increasingly complex real-world problems. There are, indeed, several examples of the dark side of institutionalized research and corporate science. Journal editors are selected based on their ability to publish papers that strictly fit within the boundaries of an increasingly shortsighted view of the particular discipline. In regard to research funding, the cabals routinely demonstrate a remarkable contempt of scientific meritocracy and principles of ethics, systematically preventing other disciplines to participate in projects with a fundamentally multidisciplinary nature.

For reasons having to do with ill-conceived policies, hidden agendas, and networks of interlocking players, too many research funding agencies (in U.S.A. and E.U. alike) have become carriers of unfairness that go out of their way to provide grants to the same groups of people that often have neither the qualifications nor the intentions to perform any kind of innovative research.[65] Naturally, in such groups, the productive tension in research is reduced to their subjects having almost nothing to do except to gaze into nothing, as do the characters of Samuel

[65] Notorious yet not atypical is the news-making case of the top administrator of a major funding agency who was forced by the U.S. Congress to resign under the weight of scandals that showed that the man was an impresario of deceit who operated on a heroic scale (Section 8.4.3.1).

Beckett's tragicomedy *Waiting for Godot*. As such, what characterizes many of these groups is their well-funded dangling over an abyss of meaninglessness and nihilism. The situation is probably related to Bruce G. Charlton's notion of *Zombie science*. According to Charlton (2009: 633): "Zombie science is a science that is dead, but is artificially kept moving by a continual infusion of funding." It comes as no surprise that, even the smallest thread of criticism is viewed by "Zombie" investigators as a clear threat to the continuation of their research funding. Scientific values and the search for truth are nowhere on their radar screen and, what is even worse, the same is true for their sponsors. Last but not least, if there was any doubt about the sad state of affairs in the research grant system, Dr. Richard D. Klausner, former director of the National Cancer Institute, eloquently summed up its complete bankruptcy (Kolata 2009): "There is no conversation that I have ever had about the grant system that doesn't have an incredible sense of consensus that it is not working. That is a terrible wasted opportunity for the scientists, patients, the nation and the world."

1.6.2.1 The State of Cognitive Dissonance

In a way, the dark side of science described above is closely linked with "professional correctness," and the occasional scientific dishonesty that accompanies it. Some psychologists associate this situation with the so-called *cognitive dissonance*: the investigators' strong tendency to favor data and methods that confirm their views, and to ignore those that disconfirm them. This phenomenon is hardly surprising. As Jacques Barzun wrote, during the time of Decadence (Barzun 2000: xx): "The stages of development have been run through. Institutions function painfully. Repetition and frustration are the intolerable result. Boredom and fatigue are great historical forces." In the same spirit is Luchino Visconti's observation: " It seems that boredom is one of the great discoveries of our time." A number of interesting observations refer to the state of cognitive dissonance established by shadow epistemology. David F. Horrobin notices that the real motivation of many journal editors can be found in the fact that, "Peer review is also the process that controls access to funding...There might often be only two or three realistic sources of funding for a project, and the networks of reviewers for these sources are often interacting and interlocking" (Horrobin 2001: 51). Indeed, if the ruling elites make sure that the competing works fail to pass the journal peer-review process, it can well mean that the competing projects are never funded. Therefore, it may be not an accident that some funding agencies even have their own research journals. In which case, it is difficult to avoid the impression that all the resources seeking absolute control of the research funding and publication process are mobilized here. Sure enough, a survey of members of the scientific research society showed that "only 8% agreed that 'peer review works well as it is' " (Chubin and Hackett 1990: 192). A U.S. Supreme Court decision that questioned the authority of the clerkdom-controlled peer-review process emphasized that (Horrobin 2001: 51), "peer review might sometimes be flawed . . . therefore this criterion was not unequivocal evidence of validity or otherwise," and that "a recent analysis of peer review adds to this controversy by identifying an alarming lack of correlation between reviewers' recommendations."

Nonetheless, the powers that be are totally immune to any sort of criticism and intervention, which is a clear testimony to the fact that the ruling elites know very well, indeed, how to take advantage of the profoundly degenerate political and social systems characterizing the time of Decadence. As a result, a tragic fate awaits those few who dare criticize the views of the elites, especially when the criticism is sound and well documented. "If you want to control someone," a life-time member of a funding agency review panel once said (Horrobin 2001: 51), "all you need to do is to make one feel afraid... Those who disagree are almost always dismissed in pejorative terms such as 'maverick,' 'failure,' and 'driven by bitterness'." Designed by impoverished minds to attack anyone who stands in their way, these labels are so banal and fatuous that their human targets feel more insulted by their banality and fatuousity than by the labels themselves. As regards those brave souls who the power holders find difficult to make the subject of their smear campaign, they are systematically marginalized and ignored.

1.6.2.2 Public Confidence

The pronouncements of science need to be greeted with public confidence, but there exists an increasing amount of evidence suggesting that this confidence is rather low nowadays, and continues to erode. It is not uncommon that the clerkdom's tactics described above (including ill-conceived professional correctness, controlling access to funding, unfairly eliminating competitors, and embracing a brutal form of utilitarianism that ignores the need of meaning and purpose in people's lives), if left unchecked, can lead to severely damaging situations as far as the science's image is concerned, including fraud and misconduct in research matters (Section 8.4.1). Bruce G. Charlton maintains that, "such is the endemic state of corruption that an insistence on truthfulness in science seems perverse, aggressive, dangerous, or simply utopian" (Charlton 2009: 633). Decadence shapes much of practical life and the noetic outlook of modern societies. In a widely publicized case, the hacking of a large number of e-mails held on the webmail server at the UK's Climatic Research Unit (CRU)[66] revealed that an elite group of researchers had been involved in a scheme aiming at silencing scientists who disagreed with their views. This incident has caused unprecedented damage to the credibility of science in the eyes of the public, and has been characterized as the greatest scandal in modern science. Fred Pearce, a UK science writer called it "Climategate," and pointed to the urgent need for researchers to operate with greater transparency, and to provide more open access to data. In a *Yale Environment 360* column, Pearce wrote:[67] "I have been speaking to a PR operator for one of

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[66] University of East Anglia, Norwich, UK.

[67] Pearce F., December 10, 2009: http://www.e360.yale.edu/content/print.msp?id=2221

the world's leading environmental organizations . . . His message is clear . . . It has always been hard to persuade the public that invisible gases could somehow warm the planet, and that they had to make sacrifices to prevent that from happening . . . But he says all that ended on November 20. 'The e-mails represented a seminal moment in the climate debate of the last five years, and it was a moment that broke decisively against us. I think the [CRU] leak is nothing less than catastrophic.'

To put it plainly: when it comes to exposing clerkdom's dark side and its negative effects on the dignified goal of many honest scientists to develop a comprehensive and internally coherent worldview, one would have thought that it is one's duty not to be afraid of words. The point has been reached when "niceties" should be considered as something one can no longer afford. Otherwise, the continuing decline in public's confidence in science can seriously inhibit crucial decision-making. One might have expected that in this degenerate state of affairs, constructive criticism and self-reflection should be society's last resorts. Constructive criticism could help scientists and policymakers think differently, reflect on their own and others' perspectives, and use these insights to develop better policies that benefit science and the society at large. Alas, as we will see below, usually this is not the case.

1.6.3 The Creation of Ethics-Free Zones

Let us ponder on the real difficulty of constructive criticism (Issue *d* of Section 1.6.1), and the potentially serious consequences that it can cause to human inquiry, including the ability to produce logical, powerful, and insightful arguments. In the process,some critical questions will emerge about who we are and what makes life worthwhile.

1.6.3.1 The Diminishing Role of Constructive Criticism, and the Dominance of Indifference

Criticism has always been an essential ingredient of human inquiry. At the very moment of the birth of philosophy in Greece, the thinkers called into question the collective, established representations, ideas about the world, the gods, and the good civic order (Castoriadis 1996). Historically, a prominent characteristic of the western civilization has always been the capacity to undertake self-criticism, for internal contestation, for challenging its own institutions and its own ideas, in the name of a reasonable discussion among human beings that remains indefinitely open and that recognizes no ultimate dogma. Let me remind the readers of three representative examples. Famous, of course, is the case of Socrates (Section 1.3.2). He was fearless in his criticism of established perspectives and assumptions, and in his relentless unmasking of poor reasoning. This approach did not make him popular with the clerkdom of the time, but he was indifferent to such matters. Many centuries later, in his "Letter to Arnold Ruge," Karl Marx (1944) expressed his strong support of a "ruthless criticism of all that exists." Also, Karl Popper's falsificationist philosophy maintains that scientific inquiry relies on the search for highly critical means that can refute a hypothesis, proposal, or theory (Section 1.1.2).

Even worse than the lack of constructive criticism is human *indifference*. Many thinkers believe that it is a rule that applies to a majority of people: when they become comfortable in their own lives, they show a remarkable indifference to the problems of others who have not been as lucky as them. Martin Luther King Jr. used to say that, "The greatest impediment to the civil rights movement was not the racists but the indifference of otherwise good people" (Ford 2007: 21). Even stronger, in this respect, is the view of Bruno Jasienski: "Do not fear your enemies. The worst they can do is to kill you. Do not fear your friends. At worst, they may betray you. Fear those who do not care; they neither kill nor betray, but betrayal and murder exist because of their silent consent." Indifference and silent consent, with their tragic consequences, do not characterize common people only. Many intellectuals have abandoned their critical role for reasons that range from poor understanding of what really is at stake to selfishness at its worse. This is an extreme state of *egocentric individualism* (Section 1.11.2), which has allowed monstrous ideas and practices to occupy the empty space.[68] Very few people choose to expose themselves to unpleasant truths. Under the widely spread influence of the illusion of perpetual optimism, even the most rational and constructive criticism is mislabeled as "grumbling," "resentment," "sour grapes," "vengeful passion," "nonprofessional," or even "antipatriotic," and is dismissed accordingly. Sad as it is, when noblemen or noblewomen of thought become the target of clerkdom's slandering tactics, they are often abandoned even by their own colleagues. Characteristic, in this respect, are Einstein's words: "The world is not dangerous because of those who do harm but because of those who look at it without doing anything."

In a consumer society that manifests a deep abhorrence of intellectual activity, and deludes itself boasting of its common sense principles and uncompromised pragmatism,[69] any attempt to criticize the negative signs of the phase of civilization we are in can be a futile or even dangerous undertaking. Any effort to call attention to widespread injustice and destructiveness is viewed as an attempt to undermine the society's welfare. The researcher who reveals the corruption of the funding system or the civil servant who dare uncover the illegal activities of state bureaucrats are not merely spoilsports, they are often labeled "enemy of the people." It is then left, again, to the small number of noblemen and noblewomen of thought to provide the leadership needed in order to build a last line of defense against the advancing tide of Decadence.

[68] The idea, e.g., that a society's survival depends on the size of its armies rather than on its citizens' capacity to rely on the strength of their own critical thought is a poor representation of historical reality.

[69] Probably the same sort of "pragmatism" that, when it was most needed, completely failed to protect the society from the devastating effects of the worst financial crisis of recent years.

1.6.3.2 An nescis, mi fili, quantilla sapientia mundus regatur?[70]

To encourage his son Johan, who doubted his ability to represent Sweden at the Treaty of Westphalia peace talks, the Swedish chancellor Axel Oxenstierna used the now famous argument: *An nescis, mi fili, quantilla sapientia mundus regatur?* Deep believers of Oxenstierna's argument are those architects of social policy who have apparently concluded that deception, greediness, illiteracy, overconsumption, and the occasional stupidity are indispensable elements of a "well-functioning" society, which is essentially a society in a time of Decadence. A society where, as the Adornonian aphorism goes, the impoverished in spirit and corrupted in soul march joyously into the inferno that is their paradise. The facts seem to vindicate, to some extent, Carlo Maria Cipolla who in the early 1970s proposed his now famous five basic laws of human stupidity.

Real-world problem–solutions do not need "new" social policies, financial schemes, and costly bureaucracies. Instead, what is urgently needed is to develop and preserve certain fundamental moral, aesthetical, and intellectual values in a system where apparently there is little trust among the people. As the thorough investigation of Max Haller has revealed, this is the case in point with the highly corrupted and incompetent system created by an arrogant E.U. bureaucracy, also known as *Eurocracy* (Haller 2008). A system that, in order to serve the privileged Euro-elites, has declared itself beyond democratic control and rational regulation, rising above human values and social principles. In this way, the elites have created an environment in which the common citizens increasingly experience a resigned feeling that the European integration has nothing to do with their own lives, concerns, and prosperity. In a recent demonstration of lack of integration and solidarity between E.U. member states, Slovakia refused to take part in the euro-zone assistance plan for Greece.[71] A scandalous creation, to say the least, which shows beyond any doubt that the greatest danger for modern Europe is its increasing inability *to be* Europe. A fast growing number of thinkers are convinced that, by purposely eliminating intellectual debate and constructive criticism, the power holders have created an *ethics-free* zone at the heart of the European system, which has opened the road to various highly questionable policies and dubious activities with regrettable and often devastating consequences in peoples' lives. No wonder then why the ruling elites stubbornly resist any kind of open evaluation and accountability. These elites, however, should also be aware of Matthew's warning: *Ουδέν γάρ εστι κεκαλυμμένον, ο ουκ αποκαλυφθήσεται, και κρυπτόν, ο ου γνωσθήσεται.*[72]

[70] Don't you know then, my son, how little wisdom rules the world?

[71] "Slovakia Rejects Its Share of Greek Bailout." The *New York Times*, Aug 12, 2010.

[72] There is nothing concealed that will not be revealed, or hidden that will not be known: Matthew **10**:26.

1.6.4 Catharsis and Sophocles' Electra

In sum, whatever the intentions of the clerkdom might be, the time eventually comes during one's earthly existence when it is of vital importance to discover how much reality one can actually afford versus how vulnerable one allows oneself to be to the convenient yet deceptive illusions promoted by the powers that be. No doubt, the clerkdom has deprived people of the precious *catharsis* offered by intellectual debate and open exchange of ideas that they so desperately need during a time of Decadence. The crucial importance of the catharsis is vividly demonstrated in a remarkable incidence described by Simon Goldhill (2005: 215): "In 1990, a production of Sophocles' *Electra*, starring Fiona Shaw, opened in Derry, Northern Ireland, during a week when eight people had been killed in sectarian violence. The production was brilliantly acted and directed, but when the performance finished something wholly out of the ordinary happened. The audience refused to leave the theatre without a discussion of what they had watched. The play is a brutal exposure of the distorting psychological traumas which a passion for revenge creates, and the drama's shocking dissection of self-inflicted anguish spoke so powerfully to an Irish audience that to leave without the catharsis of debate proved too disturbing."

Is there still hope? The old Chinese wisdom may provide some insight: hope is like a country road; there was never a road, but when enough people walk on it, the road comes into existence. But Chinese wisdom is based on strong tradition, which is something that radical postmodernism rejects, perceiving tradition merely as a form of power play. This brings us back to the shadow epistemology issues raised in Section 1.4.

1.7 On Measurement and Observation

Understanding the nature and limitations of knowledge, and assessing its value requires a certain level of awareness regarding the knowledge sources, and the methods used to acquire and process knowledge. Sources of knowledge are of a wide variability: they may be linked to an ancient Greek papyrus discovered in the sands of the Egyptian deserts, or a silk scroll that came to light in a Chinese tomb; the fruit of a cutting-edge experiment in a modern research laboratory, or the result of an exploratory exhibition to another planet. In view of these exciting possibilities, some key distinctions linked to knowledge acquisition, processing, and communication are discussed next.

1.7.1 Important Distinctions

Access to knowledge involves some kind of a *link* between human cognition and the real-world. The significance of the situation makes it worth bringing to the readers' attention certain subtle distinctions: (*a*) The link is materialized in terms of either *measurement* or *observation*. (*b*) The link distinguishes between the measurement (observation) *process* and the measurement (observation) per se. (*c*) *Technical* versus *anthropocentric* effects of the link. There are a variety of methodological and interpretational views concerning Distinctions *a–c* (Churchman and Ratoosh 1959; Roberts 1979; Henshaw 2006 are good references, in this respect). Accordingly, an agent should obtain an adequate appreciation of the prime elements characterizing the implementation of measurement and observation notions in scientific practice, including a rigorous IPS process.

Concerning the matter of measurement versus observation, there are cases where the two coincide (e.g., measuring the number of migrating birds in a region is essentially the same as observing this number). But there are other cases where the two represent considerably different things: A measurement involves an active process, whereas an observation is a rather passive process. Measuring, e.g., the maximum heat that a metal can sustain before it starts melting is the result of certain action on agent's behalf involving the experimental setup (instruments, devices, etc.) for the measurement to be made possible. On the other hand, an observational statement of the kind "the sun rises every morning" neither requires nor is depending on any human action in order to occur. Generally speaking, a measurement or observation is a quantity (usually a number), whereas the measurement (observation) process is a procedure (an experimental or a computational setup involving one or more instruments). The latter leads to the former, i.e. by means of the respective process one assigns numbers to entities (objects or attributes) in a way that certain operations on and relations among the assigned numbers correspond to or represent measurable (observable) relations and operations on the entities to which they are assigned. One example may help. Measuring water temperature involves placing a thermometer into the water and reading the recording, assuming that the thermometer has been constructed on the basis of the relevant physical theory (thermodynamics). Hence, the temperature measurement process consists of the complete set of operations (theoretical and experimental) by means of which the mapping between heat and a temperature value is established.

Substantive issues also arise about the way a measurement (observation) acts as the link between human knowledge and evidential reality. Does a better education correspond to a higher school grade? Does what is conceived as colder temperatures correspond to lower numerical values in the thermometer scale? As before, these measurements and observations are viewed as mappings of empirical entities (heat and education levels) to quantitative entities (numerical values of temperature and grade, respectively) that preserve in the latter established operations and relations between the former.

1.7.2 When a Number Is Not Just a Number

The above and similar considerations point to the important fact that the number representing a measurement or an observation is not just a number that is manipulated mechanically by means of some computational scheme or marks some routine operations, but it is part of a wider IPS context that also includes abstract thinking.

1.7.2.1 Digging Deeper: Conditions, Content, Meaning, and Operations

There are certain *conditions* characterizing the process under which a measurement is possible and a number is obtained as a result of this measurement. The measurement of soil permeability, e.g., must satisfy some empirical laws of soil structure and fluid flow; and the experimental setup must be built in accordance with these laws, so that it is possible for the setup to assign meaningful numbers to the measurement outcomes. As such, the subject of measurement (observation) is replete with theoretical issues. A number possesses an *informational content* reflecting the theoretical background of the measurement process and characterizing the value of its specific outcome. Underlying the number that represents, e.g., an electrical conductivity measurement is a theory of electricity and an experimental setup consistent with this theory. Otherwise said, conductivity becomes $\sigma = JE^{-1}$ (where J denotes current density and E denotes the electric field) only in terms of a theory of electromagnetism. In this way, the theory assigns an informational content to the number linked to the measurement of σ.

Moreover, the informational content of a number depends on the appropriate perspective. A measurement that has little content from one perspective may have considerable content from another. In a similar way, the same numbers can have drastically different *meanings* if they represent different attributes in Nature and satisfy different *relations* and *operations*, depending on the evidential situation, including empirical relations and functions of the space–time attributes they represent. Hence, distinct quantitative treatments (algebraic, statistical, geometric, diagrammatic, etc.) may be appropriate in each case, and a certain expertise with the relevant scientific field is required so that data analysis uses operations that guarantee consistency between the empirical laws and the assigned numbers. This is a viewpoint that acknowledges measurement (observation) not only as a medium of experience, but also as a resource for generating theory and method in the study of an attribute or the solution of a problem.

1.7.2.2 The Action of Measurement and Its Quantitative Representation

The above basic facts about data content and meaning are not always appreciated by mainstream texts on data analysis. We will say more about this phenomenon and its consequences later in this book. At this point, it may be worthwhile to review a few examples that offer insight concerning the relations between measurements (observations) of attributes and their adequate quantitative representation. Determining the weight of an object q implies assigning to it a number $w(q)$, which is the weight of the object q in some units (say kg). Basic principles to be adhered to in assigning numerical weights to objects include (Adams 1966): (*i*) Relations of greater (>) and lesser (<) in weight, as determined by observations of balance comparisons, must correspond to the relations of greater and lesser numerical values of the assigned weights (if object q_1 is heavier than q_2, then $w(q_1)>w(q_2)$). (*ii*) Physical operation of putting two objects together must correspond to the numerical operation of adding their weights (if the q_1 and q_2 are physically put together, their weight will be $w(q_1 + q_2) = w(q_1) + w(q_2)$). If in some situation it was observed that for three objects, $q_1, q_2,$ and q_3, it is valid that "q_1 is heavier than q_2, q_2 is heavier than q_3, but q_3 is heavier than q_1," the standard algebraic operations between numbers (weights) cannot be used; i.e., one cannot have $w(q_1)>w(q_2)$, $w(q_2)>w(q_3)$, and $w(q_3)>w(q_1)$, in which case, one may need to invent a new kind of "algebra." Such a need is often the starting point of many great discoveries. The development of the new physics (quantum mechanics), e.g., led to the discovery of new mathematics (see, also, the fundamental differences between classic and quantum probabilities discussed in Section 4.4.4). It would be instructive to consider the case of statistical data analysis: If the operations and the results of the analysis of a set of numerical values depend on arbitrary features in the corresponding physical measurements (e.g., the units), then the statistical operations may not be appropriate and the results may not be empirically meaningful.

Theories of measurement exist for quantitative as well as qualitative systems (such systems are found, e.g., in psychology, sociology, and economics). In general, the theory includes: (*a*) a set of primitives, (*b*) a system of axioms on the primitives, and (*c*) representation and uniqueness theorems. The sets in Item *a* are endowed with a specific structure together with a group of relations on these sets. The axioms in Item *b* describe the manner in which the relations in Item *a* order and bind together the structure and also postulate structural properties not represented in the relations. In Item *c*, the representation theorem determines the mapping from the qualitative system into a numerical system in a way that preserves the main features of the qualitative relations, and the uniqueness theorem identifies the kind of mappings that lead to the same quantitative characterization (Roberts 1979; Henshaw 2006).

1.7.3 We Are That Which Asks the Question

Most kinds of evidence are subject to the circumstances under which they are collected, including the agent who collected them, and the theory that connects them to human knowledge (*theoryladenness* of evidence). This is the essence of the *Heisenberg–Einstein context principle*, "It is the theory that decides what can be observed," which connects and integrates theory with experiment in an inconsistency-free manner. This does not mean that there are no entities (facts, objects, data, etc.) that exist outside of theories. As we will see in various parts of the book (e.g., Section 3.6.2), there are: (*a*) entities that exist independent of theories (e.g., pieces of metal), yet their observation has a specific meaning in the context of a theory; and (*b*) entities that do not exist independent of theories (e.g., banknotes are no more than pieces of paper without the observer's mind to think of them in the context of a financial theory).

1.7.3.1 Observer Versus Actor

The available in situ evidence and the agents involved may introduce certain *technical* and *anthropocentric*[73] features and effects, among which the following are noteworthy: (*a*) Specific features and limitations of the observation or measuring *instrument* used to collect data (e.g., the instrument may focus only on a few aspects of the phenomenon under investigation and/or may generate a set of samples in a limited subarea of the target domain). Surely, the above features are closely linked to the financial and other resources available. (*b*) Specific features and limitations of the *observer* (qualifications, professionalism, and psychological state). Assessment and interpretation of the evidence is influenced by the observer's conceptual framework, theoretical background, ultimate presumptions, and personal values. On reflection, it makes sense to use the term *actor* rather than observer.

These key issues did not just arise in recent times. Rather they have been the main concern of a number of influential thinkers of the far past. As early as the sixth century BC, the Milesians[74] did not accept that what one sees is necessarily the same as what is true. Unlike ancient Egyptians and Babylonias, early Milesian philosophers were not satisfied with answers that relied merely on religious or supernatural explanations. Instead, they were searching for answers based on some kind of underlying order or logical reasoning. In this sense, these were what today one may call "scientific" answers. Also, Heraclitus (Section 2.2.1) argued that the knowledge obtained by an agent's senses is inevitably observer-dependent. He even came up with a now famous example, sufficient for a layperson to understand his line of thought: "A mountain," Heraclitus noticed, "seems to go both up and down, depending on where the observer is standing at that time." Several centuries later, in his work *The Assayer* (Redondi 1987), the great intellect of Galileo Galilei offered an acute observation concerning the anthropocentric process: "Tastes, colors and smells exist only in the being which feels." In a similar vein, the German novelist, poet, playwright, and natural philosopher Johann Wolfgang von Goethe famously observed that, "Were the eye not attuned to the sun, the sun could never be seen by it." The message of Goethe's observation is that, if human agents had

[73] Not to be confused with the egocentric features of ill-conceived individualism (see later in this chapter).

[74] They were given this name because they lived in Miletus in the sixthand seventh centuries BC. Among them were Thales, Anaximenes, and Anaximander.

evolved in a different way (as part of their evolutionary adaptation), they might possess different sense organs and brains and, as a result, they might have a different perception of the world than they currently have. In the footsteps of Galileo and Goethe, the eminent twentieth century physicist Werner Heisenberg emphasized the interplay between Nature and human agent: What the agent observes is not Nature itself, but rather Nature exposed to the human method of questioning, which may differ depending on the in situ circumstances and the agent's mode of thinking. Heisenberg's perspective had a major influence on the conception and development of much of modern physics.

1.7.3.2 Matters of Interpretation

In view of the above considerations, working with the notions of measurement and observation brings to the fore a number of intriguing anthropocentric items: There is a wide range of issues associated with evidence acquisition and the conceptual framework within which *interpretation* can proceed. Theory and concepts often come before measurement (observation), in which case the world perspective introduced by the former can significantly affect the outcome of the latter (Section 1.2). The adequate representation, e.g., of the observation statement "The molecular structure of the fluid is affected by heating" presupposes knowledge of elaborate theories developed by human agents (molecular physics, thermodynamics, etc.). Looking through an electron microscope, a trained physician and an attorney do not see the same thing. They are both "actors in the same play," so to speak, but the former is a much better actor than the latter, as far as the specific "play" is concerned.

Scientific inquiry is an economical affair, in the sense that scientists do not just measure or observe, recording each and every aspect of a phenomenon. Instead, they choose which aspects to concentrate on. This choice involves decisions that are related to one's *worldview*. Expectation regarding what an agent is likely to measure or observe affects what the agent actually does measure or observe. Just like theories, scientific instruments are human creations too. These instruments are sensitive only to certain kinds of input and, so to speak, blind to all others. Their outputs are perfectly controlled by the input and the internal structure of the instrument. An instrument is often a complex structure that is built according to a particular *paradigm*.[75] Using a current paradigm to interpret data obtained in the past may lead to distortion. There are many cases where the interpretation of key concepts (such as mass, force, and energy) has changed in time to the extent that they became *incommensurable*.[76] To discuss the ancients' chemical theories and data, e.g., is bound to distort what they were doing, since chemistry as understood today is a product of the eighteenth to nineteenth centuries (Lloyd 2007).

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[75] This is a term introduced by Thomas Kuhn (Section 2.2.15) to describe a particular way of looking at things, including a theoretical perspective and conception of what is measured.

[76] The reader is reminded that incommensurability involves the inability to translate some concepts of one tradition into meaning and reference in some other tradition.

1.7.3.3 Measurement and Existence

In many cases, measuring something does, indeed, prove its physical existence in a definite and unarguable manner (e.g., measuring the weight of a chair implies its physical existence). In some other situations, however, matters are more complicated. *Time* has been and continues to be one of the most fundamental yet heavily debated concepts in the history of science (Lanza 2007). People measure time using clocks. But in measuring time, does it prove that time exists as an observer-independent entity? Einstein, for instance, tried to sidestep the issue by simply defining time as "what we measure with a clock." Einstein's emphasis was on the "measure," whereas from another viewpoint the emphasis should be on the "we." According to the latter viewpoint, measuring time does not prove its physical existence. One can use the rhythms of some events (like the clicking of clocks) to time other events (e.g., the rotation of the earth). This is not time, but rather a *comparison of events*.

Just as measuring something does not necessarily prove its physical existence, so having a memory of something does not always prove its physical existence. This memory condition particularly impressed Gabriel Garcia Marquez, as is evident in the following passage from his novel *Memories of my Melancholy Whores* (Garcia 2005: 59): "Some real events are forgotten, whereas some others that never were can be one's memory as if they had happened." The situation featured in this passage has to do with the way the brain works and its relationship with mind functions (Chapter 3). Directly related to Garcia Marquez's passage are important scientific questions, such as: Why things that do not exist sometimes are stored in memory as real? Why things that exist sometimes feel unreal? How are such matters influencing an agent's cognitive condition in relation to real-world problem-solving? Research in neurophysiology has shown that when brains perceive the world, there are some errors that creep into its information processing (Johnston and Wu 1994; Kandel et al. 2000; Purves 2007). A standard result of cognitive theory is that what an agent sees in an empirical sense, by means of sensory brain regions, is affected by what the agent expects to see in an abstract sense, in terms of the mind's mental states (Gazzaniga 2000b; Dauwalder and Tschacher 2003). In other words, the motto "seeing is believing" in some cases is turned around to "believing is seeing." This implies that what an agent sees and stores in memory is not necessarily out there. In certain cases (e.g., under stressful, unexpected, or frightening conditions), input from memory in the form of unreal imagery may fill the vacuum created by sensory loss. Scientists have studied ways for the effective visual representation of information using principles from neurophysiology and psychology. These ways can optimize how agents perceive visual information, thus resulting in improved clarity and utility (Ware 2004). In this effort, the practical significance of the "actor" perspective is emphasized by the fact that observations obtained by a human visualization device (e.g., the eyes) may be inaccurate representations of the real phenomenon. Experiments in cognitive sciences have shown that human eyes often may not be seeing what is actually in the real-world, or they may obtain distorted pictures of reality (Penrose and Penrose 1958; Kanizsa

1979; Wade 1982; Rock 1995; Bach and Poloschek 2006). If similar cognition matters are not properly detected and assessed, they can have a negative effect on the IPS process.

Let us conclude this section with Sir Arthur Eddington's poignant observation:

> What is the ultimate truth about ourselves? Various answers suggest themselves. We are a bit of stellar matter gone wrong. We are physical machinery – puppets that strut and talk and laugh and die as the hand of time pulls the strings beneath. But there is one elementary inescapable answer: *We are that which asks the question.*

Taking this into account, one is prompted to ask whether it is the observer or the actor who can pose and answer such a critical question in the best way.

1.8 Feynman's Wine and the No-Man's Land

Most readers would agree that the two critical steps considered by those working in the frontier of research and development are: (*a*) the discernment of important phenomena, and (*b*) the introduction of appropriate conceptual frameworks that represent them as definite problems. Step *a* requires the fruitful combination of innovation, insight, and vision. The framework chosen in Step *b* is critical, in the sense that a phenomenon totally opaque in one representation may become obvious in another. With increasing frequency, many important problems in Step *a* and their conceptual frameworks in Step *b* have a *multidisciplinary* character. If history of science is any guide, progress is often the result of integrating wider fields of study or disciplines, as they came to be known in the scientific jargon. In modern times, more than ever before, many sciences are linked together and advance in concert. A remarkable property of this integration is that it accounts for the fact that every discipline represents a body of knowledge *and* a point of view. This property is at the crux of a rigorous IPS approach, which involves a play of tensions between the disciplines, and a system of checks and balances whose extension delineates the IPS width, length, and depth.

An appropriate distinction could be made between two kinds of multidisciplinary activities: *Intradisciplinary* refers to integration activities between subfields of the same scientific field (the subfields of obstetrics, gynecology, and pediatrics in medicine; the subfields of statistical mechanics and thermodynamics in physics). *Interdisciplinary* considers the synthesis of different fields (fluid mechanics, toxicology, systems theory, and epidemiology in population exposure studies; problem–solution in biomedical engineering involves tissue engineering, imaging, gene therapy, and device design). In his study of the relations between different sciences (interdisciplinarity), Richard Feynman used the metaphor of a glass of wine, in which he saw a synthesis of scientific disciplines like physics (fluid dynamics and optics), chemistry (array of chemicals), biology (life of fermentation), geology (mineral nutrients), and psychology (pleasure of drinking). The purpose of the metaphor was to draw attention to in situ conditions that allow many disciplines to investigate the same in situ phenomenon, thus giving rise to a coherent interdisciplinary study of the phenomenon.

Some scholars have gone beyond Feynman's metaphor arguing that at the creative moment boundaries between disciplines dissolve, in which case excessive disciplinary specification can be actually an obstacle. A fascinating example is the discovery of DNA by Francis Crick and James Watson. According to Richard Ogle (2007: 34), "One of the principal advantages Crick and Watson had over their rivals lay in what at first might appear to be a weakness: their failure to specialize in any one discipline. The upside of this was the relative ease with which they moved from one discipline to another, multiplying the number of different idea-spaces they could think with."

Beyond doubt, multidisciplinarity (in its various forms) reigns supreme in modern brain sciences (including neuropsychology, cognitive science, and evolutionary biology), which explore the exciting opportunities, as well as perils, generated by the process of transcending disciplinary boundaries. Epibraimatics' interest is the quantitative study of problems that belong to various disciplines and to the "no-man's land" in between. As such, Epibraimatics may be not particularly appealing to professionals of narrow disciplines but rather to uncommitted individuals with inquisitive minds.

1.8.1 A Need for Synthesizing Thinkers of Large Scope

The meaning of key cognition concepts transcends various disciplines (Section 3.2). This implies that in many cases the investigators must possess the ability to cross over into new conceptual domains and utilize their intelligence.

1.8.1.1 Multidisciplinarity and Knowledge Synthesis

When considering a multidisciplinary problem, the knowledge sources to be integrated by means of an IPS approach may differ in terms of facts, empirical data, ultimate presumptions, theories, models, and thinking styles. The Black Death mortality maps (Fig. 1.1) are the outcome of a synthesis process that involved numerous knowledge bases, including hospital data, ecclesiastical documents, court rolls, chronicles, guild records, testaments, church donations, letters, edicts, tax records, financial transactions, land desertion patterns, tombstone engravings, history documents, and artistic creations (paintings, poems, etc.). Concerning the latter, valuable information is obtained from paintings of the time, which supports the view that art is really tacit experiential knowledge. The contributing investigators maintain their different perspectives: For example, while a historian seeks to describe, explain, and interpret what happened during the fourteenth century Black Death, the epidemiologist aims to understand how and why the Black Death epidemic happened. The devastating effects of Black Death in the British Isles are vividly described in Benedict Gummer's book that is based on the insightful synthesis of historical data, sociological perspectives, and scientific modeling

(Gummer 2009). Steven Johnson (2007) describes how multidisciplinary thinking (involving the intertwined histories of disease spread, the rise of cities in nineteenth century England, the cultural realm of ideas and ideologies, and the different modes of scientific inquiry) offers an informative account of the most intense cholera outbreak to strike Victorian London, and also furnishes an explanation of the way it affected the entire world. In the study of neural tube defects in Heshun county, China (Fig. 3.1a), the IPS process involved information about social systems like gross domestic product, and the distribution of doctors. In such cases, unlike physical systems, a social system is composed of thinking agents, which implies that there could be an interaction between the theory describing the social system and the social system itself (often, one of the main goals to develop a social theory is to change the social system).

The strands of many modern disciplinary braids cannot be unraveled, dissolved, or systematized into a single approach. Wendy Newstetter (2006), e.g., emphasizes the immense learning challenges of a biomedical engineer who has to be "fully conversant in three intellectual traditions, which are often at odds with one another and have historically been taught by distinct faculties. For an individual to reconcile these disparate practices and historically separated intellectual traditions she/he will need cognitive flexibility and true integrative thinking." Indeed, a biomedical engineer may have to develop multidisciplinary skills and knowledge in biology, chemistry, computer science, and engineering (quantitative skills of traditional engineers, qualitative features of a more biological approach, and exposure to patients and doctors).

1.8.1.2 Flying Blind Among Mountains of Diverse Knowledge

Embracing the multidisciplinary perspective of IPS is by no means a trivial matter. One can find in the literature several studies that replace the meanings of the composite elements with their external features, thus leading to a synthesis that takes the form of a patchwork. As Thaddeus R. Miller and co-workers have pointed out (Miller et al. 2008: 48) many interdisciplinary studies "end up entitling a single discipline or epistemology, incorporating others in a support or service role—we can refer to this as "epistemological sovereignty" (Healy 2003)." Moreover, what makes things more complex is that a multidisciplinary study is often considered merely as the mechanical processing of numerical data, ignoring a host of important issues such as the considerable differences in the substantive meaning of data that come from different sources, the varying scientific theories and reasoning modes underlying data acquisition, and the effect of incommensurable belief systems (Nychka and Saltzman 1998; Zeger et al. 2000). Indeed, the price to be paid for this situation can be very high. When the problem is inherently multidisciplinary, focusing on pure "data massaging" and "number crunching," or restricting oneself to the domain of one's discipline is a convenient approach, but can lead to an incomplete assessment of the in situ situation, poor appreciation of important problem features, and the derivation of inadequate problem–solutions.

In the IPS setting, usually no one of the disciplines involved can stand alone as an authority. One of the advantages of the multidisciplinary approach to IPS is that investigators of one discipline can become aware and learn from substantial developments in the other specialties. In many cases, the answer to a question in one discipline already exists in journals of other disciplines, waiting to be assembled by the scientist willing to read across specialties. Ignoring developments across disciplines is like flying blind among mountains of diverse knowledge sources and facts that are being ignored (because they contradict the disciplinary vision that gives many investigators their sense of self-worth).

1.8.1.3 The Value of Empathy

Scientists working in multidisciplinary projects learn to fully appreciate the considerable benefit of understanding each other's thinking styles and experiences based on *empathy* (in the sense of understanding and vicariously experiencing the thoughts and experience of another agent without having the thoughts and experience fully communicated in an objectively explicit manner). This is not a small matter. The inability to experience the "otherness" to an investigator's own consciousness (that is, the consciousness of a human agent other than oneself) can lead to certain limitations in intuition based on empathy that cannot be ignored.

The readers may applaud the suggestion that many scientists could learn something valuable from painters like Vincent Van Gogh, who tried to paint the others as "subjects" and not as "objects." Van Gogh completed his 1883 drawing *Potato Grubbers* only after he had lived with the peasants, in an effort to develop that structure, which made possible for him to experience their "otherness." Similarly, when he was working on his epoch-making 1907 painting *Les Demoiselles d'Avignon,* Pablo Picasso used to visit the St. Lazare hospital in Paris to observe the prostitutes interned there. The message to IPS theorists is that they may need to spend time observing the techniques of the experimentalists, and vice versa (see Section 2.5 for an analysis of the potentially negative effects of the lack of such a collaboration). Similarly, scientists of one discipline involved in the solution of an interdisciplinary problem may need to become sufficiently familiar with what happens in the other disciplines.

By now, it has become clear that the lack of synthesizing thinkers of large scope can have a negative effect on the development of a discipline. Under the influence of the PCU mindset, many colleges have been developed on the basis of a strange combination of ill-conceived professional correctness and business-like rules, thus failing to create an environment that appreciates empathy and can support independent thinkers capable of binding divergent yet valuable ideas into a larger whole. The fact that these disciplines are currently based on assumptions that are incompatible and outdated does not seem to bother the campus administrators who are more interested in the advocacy of agenda-driven policy positions and avaricious aims than in academic ideals and moral principles.

1.8.2 When Microscale Research Is Not Miniaturized Macroscale Research

Generally, a *system* is viewed as a collection of related elements organized according to a plan and forming a unity. In the case of an epidemic, e.g., the system includes the infection agents, exposure pattern, population (susceptibles, infecteds, and removed), medium within which the epidemic propagates, lines of infection, contact processes, as well as their relations and interdependencies in a space–time domain (Wang 2005).

1.8.2.1 Open and Closed Systems

It is widely recognized that in real-world situations, the focus of an IPS study should be an *open* system rather than a *closed* system. An "ideal" closed system (usually associated with curiosity-based scientific research) operates in a controlled environment where the laws of symbolic logic apply. Often, these systems are convenient products of the imagination, mainly serving the purpose that the existing mathematical techniques can be used meaningfully to understand certain important elements of the underlying phenomenon. On the other hand, in an open system (associated with science as a basis for action), the input parameters are incompletely known, uncertain influences and outside dependencies exist, and the content-free rules of symbolic logic will not suffice.

Since many in situ investigations of open systems involve several different disciplines, how exactly should one conduct scientific inquiry in a multidisciplinary domain? This is yet another key methodological question that arises from the fact that the investigator considers interacting attributes defined in different disciplines, and seeks to study their behavior as an open system under diverse influences and conditions of uncertainty. The answer to the above question requires a conception of proper methods to be employed, an appraisal of the relative merits of the methods considered, and their adequate justification in an IPS context. An investigator's analysis of aspects of a multidisciplinary phenomenon should be relevant for understanding the phenomenon, and any insights it produces are accountable to the needs of reason reflecting upon in situ experience. In sum, when used properly, the concepts and techniques linked with both the closed and the open systems can serve distinct yet vital objectives of scientific inquiry. Consideration of a closed system by means of thought experiments (Section 2.4.2) helps sharpen one's ideas, stripping away elements (real or imaginary) that complicate matters so that one can focus on essential problem aspects and gain valuable insight. The study of open systems, on the other hand, is necessary when a variety of content- and context-specific factors, auxiliary conditions, and multidisciplinary considerations play a key role in the action-oriented solution of a real-world problem and influence its scientific, social, political, economical, and ethical consequences. Also, the significance of studying an open system directly is further emphasized by the fact that neuropsychological research studies have clearly shown that findings derived on the basis of closed systems do not necessarily generalize to real-life open systems.

1.8.2.2 The River, the Bucket, and the IOED

As many readers are aware, the considerable confusion between closed and open system conditions can cause serious problems. Arguably, a careful description of the environment should be in terms of an open system, which includes its major components, auxiliary conditions, and essential interactions (Peng et al. 2001). If neglected, these system features can lead to serious misinterpretations and nonsensical conclusions. Despite this and similar warnings, more often than not investigators seem to believe that they are working with an open system when, in fact, they effectively limit themselves to a closed system that has little or nothing to do with reality. In cognitive sciences, this phenomenon has been termed the "illusion of explanatory depth" (IOED; Rozenblit and Keil 2002). IOED describes how investigators overestimate their understanding of complex natural phenomena. Some characteristic examples are discussed next.

When it comes to experimental studies of subsurface environments, an expensive laboratory instrument that shines is not a substitute for methodological coherence, theoretical understanding, and innovative experimentation. For many years, what has escaped the attention of certain laboratory studies of fate and transport (Illangasekare 1998, 2009) is the elementary fact that microscale research is not miniaturized macroscale research. If one happens to read the "findings" of this sort of laboratory research, it is impossible to understand which scientific theory and in what way guides the experiments; what exactly the experimental conditions are and whether represent the in situ phenomenon in a realistic manner; and which ones of them are likely to affect the results. Because these issues are not seriously taken into consideration, useless or trivial (at best) results are produced, smiling cheerfully all the while. As a result of this flawed thinking and associated IOED, it is not surprising that computer game simulations developed by nonscientists are often far more realistic and much less expensive than this sort of environmental research. Humor always offers relief from life's unpleasant incidents, which is probably why Alan Watts (1968) suggested that many laboratory studies closely fit the well-known metaphor: To study a river, take a bucket of water out of the river, bring the bucket to the shore, and then study it. Surely, the issue is much deeper and has graver consequences for scientific research than a simple metaphor can convey. In essence, we are dealing with a rather widespread IOED phenomenon, in which fiction triumphs over substance, it has the ability to make a real success of charlatanry, and also it makes the most chimerical research projects appear as grand visions of the future. This is the sort of mythmaking[77] binge that is puzzling as is infinitely saddening.

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[77] As a nation of immigrants lacking a common ancestry and tribal ties, from its very beginning America was built on myths. Naturally, its modern era myths are far more involved as a result of a huge and powerful media network that dominates every sector of the society.

1.8.3 Identity of Composition Versus Identity of Definition

An open system may involve several attributes varying across space–time. Often, these attributes are *composite*: Their representation at a certain space–time scale involves the study of more than one *constituent* attribute. This distinction may be a convenient mental construction, or it may be based on hard-to-ignore in situ considerations. In any case, the question arises how the composite attributes of the system as a whole are related to the constituent attributes. Under certain circumstances, it may be possible to apply a kind of isolation condition claiming that the composite attributes of the structured whole are, in some sense, mirror images of the constituent attributes. The behavior of the composite attributes in the structured whole can be then derived from the constituent attributes plus statements describing the organized structure in which they are bound and the prevailing system conditions. In many other situations, however, an underlying connection condition applies, in that it is impossible to understand how the composite attributes of the structured wholes function by simply studying the corresponding constituent attributes in isolation conditions (this is the case of emergent attributes, among others).

1.8.3.1 Interdisciplinary and Intradisciplinary Composition

There are a number of possibilities with regard to the constituent attributes (considered in individual disciplines) and the composite problem (considered in the interdisciplinary context), such as: (*a*) Constituent attributes may be characterized by varying sources and levels of uncertainty, and they may exhibit spatiotemporal dependence features that do not coincide with those of the composite attribute. (*b*) Mental entities (theories, reasoning modes, metaphors, and thought experiments) used to describe attributes in one discipline may differ considerably from those used in another; i.e. human knowledge of these attributes may be epistemically diverse. (*c*) One should distinguish between the *interdisciplinary composite* (IeC) attribute and the *intradisciplinary composite* (IaC) attribute. The IeC arises from the synthesis of constituent attributes in different scientific disciplines. The IaC, on the other hand, is linked to constituent attributes within the same discipline.

It is noteworthy that even if the individual features of the constituent attributes vary considerably, the composite features may be preserved, giving rise to the composite attribute. Let us consider some examples. The interaction of large numbers of constituent gas particles with individual masses and velocities (statistical physics) gives rise to gas temperature (IaC) in thermodynamics (i.e., the laws of ideal gases emerge from the extremely chaotic motion of numerous individual particles). The individualities of each particle can be ignored and, instead, one focuses on their group or average characteristics that yield the IaC. A similar reasoning applies in economics: while the behavior of an individual person may be impossible to study, one can describe the behavior of large populations for which statistical regularities emerge.[78] In population exposure studies, the synthesis of knowledge concerning pollutant concentration (atmospheric chemistry), biologically effective dose (toxicokinetics), and population dynamics (demographics) gives rise to disease incidence (IeC).

There are counterexamples, as well. Although the psychological behavior of individual people is, understandably, very difficult or even impossible to predict, the same is valid for the behavior of large populations of individuals. In other words, unlike populations of material particles with different physical features, statistical regularity is not a feature of populations of humans with different psychological features. Another counterexample, of a different kind, is when the characteristics of the relevant composite attribute are valid but cannot be explicitly reduced to those of the constituent attributes. In the example discussed in Ervin László (1972: 9), it is impossible to predict the number of fatal accidents on a July 4th weekend by studying the features of each individual driver on the road (abilities, mental states, routes, etc.). However, by taking the individual drivers as a group (July 4th motorists), and considering past patterns of the group's behavior together with the road conditions, number of cars in service and the like, it is possible to derive an accurate prediction of highway deaths on a July 4th weekend. Clearly, the group (composite) has characteristics of its own that are not reducible to those of any individual driver (constituent).

1.8.3.2 Emergence: "Is" Versus "Made Up"

To say that a composite is *made up* of certain constituents, it is not to say necessarily that it *is* simply their summation. In fact, the *emerging* attributes characterizing the composite problem often differ considerably from the constituent attributes of individual disciplines. Macroscale properties of physical objects (e.g., the solidity of a piece of wood, or the liquidity of water) are composed of interacting particles at the microscale and can even be causally explained by the behavior of these particles. Nevertheless, such macroscale properties are not the same thing as a system of interacting particles, but they rather emerge from the microscale behavior of these particles.

One may argue that the situation described above is true in a wider sense: identity of composition does not necessarily imply identity of definition. According to many researchers, the fact that mental states (e.g., a thought) may emerge from the composition of physical (brain) processes, it does not imply that mental states are the same thing as brain processes. One may rather say that mental states emerge

[78] Nevertheless, as was noticed by Jean-Philippe Bouchaud (2008), economists and financial analysts do not usually welcome the study of financial problems in an integrative manner that involves scientific methods. Their faith is often placed on unshakeable dogmas rather than on scientific reasoning, conceptual frameworks, and evidential support.

from the composition of brain processes. According to Francis Crick (1994), individual brain neurons have none of the properties of what we consider to be consciousness, but by working together they can generate consciousness, in the sense of awareness that may affect reality (Section 3.2.3). This view (also known as physicalism) is not without opposition (Nagel 1987): researchers of the nonphysicalism camp ask how nonphysical states (e.g., consciousness) can emerge from physical quantities (e.g., brain neurons). In other words, while in physical sciences the material entities at the microscale give rise to material entities at the macroscale, in brain sciences it seems conceptually incoherent to assume that the nonphysical entities (mental states) emerge from physical entities (brain neurons). But we will return to this very important topic later in this book.

1.8.4 The Para-Oedipal Act

As noted earlier, one of the biggest obstacles to progress in IPS is the narrow-mindedness and uncompromising disciplinism instituted by the careerists of the various fields involved in a multidisciplinary study. Among other things, one finds scientists who avoid referring to the work of others who have profoundly and deeply influenced their thinking and writing. This is known as the *Para-Oedipal act* (Bloom 1997), i.e. killing one's literary father, the person who most influenced one's writing and, hence, with whom one strives not to be associated.

1.8.4.1 Thor's Goats

There is a plethora of examples of the Para-Oedipal act and its consequences, small and large, local and global, scientific and societal. Due to space limitations, we will limit our discussion to only a few of these examples. Well known is the case of the structure function originally introduced in turbulence studies (Kolmogorov 1941). The same function was later rediscovered and renamed in at least two different fields: as the serial variation function of time series analysis (Jowett 1955), and as the variogram function of geostatistics (Matheron 1971); see Section 5.7.1. Fractal random fields (Mandelbrot and Wallis 1968; van der Ziel 1970) became popular tools of applied sciences during the 1980s and 1990s (Voss 1985; Feder 1988; Elliott et al. 1997). Similar is the case of wavelets that have been used (*inter alia*) in signal analysis and image processing (Daubechies 1992; Chui 1997; Benedetto 1997). Remarkably, a little acknowledged fact is that fractal and wavelet fields essentially constitute a special case of the wider class of generalized functions or fields originally proposed in the 1950s (Yaglom and Pinsker 1953; Itô 1954; Gelfand 1955; Yaglom 1957). Indeed, fractals and wavelets could find an elegant and fruiful description in the language of generalized functions, in which case many modern results either already existed or could be derived in a straightforward manner from the richer generalized theory[79] developed several decades before fractals and wavelets become *science a la mode*. Making the appropriate associations with fundamental earlier work in a timely manner could have initiated many new developments in the study of fractal and wavelet fields.

In a sense, the above examples of scientific research somehow remind one of *Thor*'s goats (Tanngnost and Tanngrisnir) that provided an endless supply of the same meat: every time they were eaten, the Norse thunder god would wave his hammer over the remaining bones and the goats would come alive.

1.8.4.2 The "Anti-Matthew Effect and Esotericism"

Hannes Alfvén (1970 Nobel Prize in physics) made important discoveries in magneto-hydrodynamics with fruitful applications in different parts of plasma physics. An additional "distinction" is that he is yet another characteristic case of the Para-Oedipal act. As Stephen G. Brush wrote, scientists who built their careers on the basis of Alfvén's work do not acknowledge the original Alfvén's publications. "Even when they accept Alfvén's ideas, other scientists tend to ascribe them not to Alfvén but to someone else. Often, the person cited is a colleague or student of Alfvén who has written a paper reviewing or elaborating Alfvén's work," and "there seems to be a kind of 'anti-Matthew effect'[80] that takes away credit from Alfvén … and gives it to the lesser-known scientists" (Brush 1990: 27). Alfvén's case is not a rare exception. Sadly, a long line of distinguished scientists shared his fate.

A curious case of Para-Oedipal act is the intense *esotericism* of certain spatial statistics groups that makes them accessible to the initiated only (Fuentes et al. 2005; Sahu et al. 2009). At the same time, this esotericism expresses varying levels of alienation from important developments in spatial and spatiotemporal analysis that take place in many other scientific fields. Along the same lines is the case of Kriged Kalman filters introduced in an operations research setting (Mardia et al. 1998; Cressie and Wikle 2002). These models have been tested in far fewer real-world applications than the similar spatiotemporal Wiener–Hopf models of distributed parameter systems used in earth and atmospheric sciences (Tzafestas 1978; Omatu and Seinfeld 1981, 1982). To the outsiders, a prime characteristic of this sort of esotericism is a chronic inability to appreciate the work of others and cite the original sources. The situation is sometimes referred to as the optical delusion of consciousness that restricts researchers to their personal desires and to apportion for a few others professionally closest to them. Often, this way of conducting business backfires, since esotericism prevents its devotees from realizing that their

[79] See, e.g., the monumental work *Generalized Functions: Complete 5-Volume Set* by I.M. Gelfand, G.E. Shilov, and N.Ya. Vilenkin; translated in English and published by Academic in 1964.

[80] A term proposed by the sociologist Robert K. Merton, alluding to a biblical statement (Merton 1968).

techniques could have benefited enormously from those developed by other scientists long time ago.

In a broader sense, Para-Oedipal acts are closely linked to the egocentric mindset discussed in Section 1.11 and in other parts of the book. Beyond matters of scientific integrity, which seem to fall out of fashion during a time of Decadence, an objective observer cannot avoid wondering how much faster and more productive a field's growth would become if its investigators free themselves from the consciousness' delusion and make the appropriate connections with significant developments outside the restrictive boundaries of their "inner circle." The phenomenon is closely related to strong evidence that many disciplines are populated predominantly by local thinkers, who increase in number at an exponential rate. On the other hand, these disciplines are painfully lacking global thinkers, the kind of synthesizing scholars of large scope once represented by Leonardo da Vinci, Henri Poincare, John von Neumann, Niels Bohr, and Bertrand Russell, among others. The severe consequences of this phenomenon could decide the fate of the above disciplines for years to come.

1.8.4.3 The Ultimate Contradiction: Risk-Free Research

Yet, there is another, pragmatic, dimension of the disciplinary "isolation." While it adds little to scientific progress, rediscovering tools and results that already exist in other disciplines is essentially *zero-risk research*: there is no element of uncertainty in the proposed research project, which is sure to yield correct albeit mostly trivial results (as far as developments outside the investigator's "inner circle" are concerned). When one renames, e.g., the "structure" function as "variogram" function, or the "Wiener–Kolmogorov" theory as "Kriging" theory, one knowingly enters rich fields with a plethora of results to be rediscovered easily, safely, and profitably. It does not get any better than that for local thinkers of all sorts.[81] But although it may be true that during a time of Decadence, the society's loose morals justify all kinds of crimes, nevertheless, loose morals cannot make disappear elementary facts of logic: "risk-free" and "research" constitute an obvious contradiction in terms.

Alas, the inspiring motto of Renaissance humanism that encourages people to risk entering the labyrinths of knowledge and meaning falls on deaf ears. Instead, "it is entirely normal and unremarkable for scientists to spend their entire professional life doing work they know in their hearts to be trivial or bogus – preferring that which promotes their career over that which has the best chance of advancing science" (Charlton 2009: 633). Furthermore, "The cancer institute alone has spent

[81] To use a metaphor, zero-risk research resembles the "oldies but goodies" albums of the music industry that pleasantly take us down the memory lane, but do not offer any new sound, themes or genre.

$105 billion since President Richard M. Nixon declared war on the disease in 1971. The American Cancer Society . . . has spent about $3.4 billion on research grants since 1946. Yet the fight against cancer is going slower than most had hoped, with only small changes in the death rate in the almost 40 years since it began. One major impediment, scientists agree, is the grant system itself. It has become a sort of jobs program, a way to keep research laboratories going year after year with the understanding that the focus will be on small projects unlikely to take significant steps toward curing cancer" (Kolata 2009). It is disappointing that despite these legitimate concerns, the dominant institutional structures, sectoral silos and reward systems of major funding agencies (like NCI, NIH and EPA) do not actively encourage a genuine dialogue between disciplines for the benefit of scientific inquiry and the public at large.

1.8.4.4 Turf Protectionism

One would have thought that all scientists have the right to express their views freely, and it is wrong when some of them resort to unethical means in order to prevent their colleagues from doing so. True? *Non*, *Chérie*! As noted earlier, in a climate of increasing turf protectionism, not too many journal editors can be sufficiently undogmatic to publish theoretical proof or experimental evidence that runs counter to the viewpoint they have inherited. As a matter of fact, some editors will go out of their way to stifle any genuine divergency and censor dissident voices. In the widely publicized case of "Climategate" (Section 1.6.2), plenty of evidence emerged suggesting that prominent scientists have been involved in "A long series of communications discussing how best to squeeze dissenting scientists out of the peer review process. How, in other words, to create a scientific climate in which anyone who disagrees with AGW [anthropocentric global warming] can be written off as a crank, whose views do not have a scrap of authority" (Delingpole 2009). Climategate seriously damaged the public image of science but it also violated the very essence of scientific inquiry. As Stephen Jay Gould puts it, "Science is a procedure for testing and rejecting hypotheses, not a compendium of certain knowledge."

In light of the above, one is not surprised that there exist editors who censor the work of scientists in disciplines other than their own, even if this work is highly original and absolutely relevant to the scope and objectives of the journals.[82] As a result, the development of the isolated discipline is choppy and fragmented, often repeating the work that has already been done in other fields, since scientists of different orientations show little interest in drawing all the insight they could from what researchers have done in other specialties and even learn from each other. In which case, the biblical quote seems to apply: *Μωραίνει Κύριος ον βούλεται απολέσαι*.[83]

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[82] *Inter alia*, the hidden agenda is that by no means junior scientists should become aware that many relevant and important results have been derived by researchers in other fields, and not by their disciplinary "heroes."

[83] I.e., "whom God wants to destroy, He turns into a fool."

1.8.5 *Johst's Browning and Wollstonecraft's Complaint*

Culture[84] generally refers to the cultivation of individuals through education, creative action, constructive criticism, and intellectual accountability. Authoritarian regimes and dogmatic elites both dislike culture, especially the parts linked to "criticism" and "accountability." In which case, one is not surprised by the infamous quote by the Nazi playwright Hanns Johst: "Wenn ich 'Kultur' höre ... entsichere ich meinen Browning."[85] The self-regulation dogma of financial markets (Section 1.4.2) reflects a similar disdain for any sort of criticism and accountability. The same dogma is adopted by the cabals of institutionalized research and corporate science. These cabals reject theorists' criticism of their expensive experiments, in an obvious attempt to completely insulate themselves from intellectual accountability and prevent the development of a culture of integration, open collaboration, and constructive criticism in publicly funded research.[86]

1.8.5.1 The Convenient Role of Bureaucrats

As a matter of fact, it serves best the objectives of the ruling elites that the agency bureaucrats are often selected among those possessing limited cognitive power but considerable tolerance to manipulation. As far as these elites are concerned, the bureaucrats should never break out of the confines of limited vision and understand, e.g., that it is not merely expensive laboratory equipment that can determine the evolution of ideas, but primarily the ideas and conceptual work that can generate scientific and technological development. As if this was not enough, bureaucrats should never become aware of significant advances outside the elite-controlled domain, because such an awareness could very well question the supposedly "unique contribution" of the specific discipline to scientific progress and the society at large.

The above matters are well understood by the cabals, which consider it of the utmost importance that the bond between the funding administrator and the research grantee is not between their intellects but between the financial resources available on the side of the former, and the avaricious careerism it is to satisfy (and often the vacuum of substance to fill) on the side of the latter. There is plenty of evidence that most of the knowledge generated and communicated in this way is merely convenient and tautological, at best, contributing very little to the

[84] "Culture" has its origin in the Latin "cultura" stemming from "colere," meaning "to cultivate."

[85] "When I hear the word 'culture'... I release the safety catch of my Browning." This line originates in Johst's play *Schlageter* (Act 1, Scene 1).

[86] It is not without symbolism that the motivations of both the elite of financial markets and that of corporate science are strictly monetary. The former elite seeks to secure huge bonuses despite its miserable failure to prevent financial collapse, whereas the latter elite demands large-scale research funds despite its proven inability to generate original science at a similar scale.

understanding of the subject and to its future advancement. Sign of the times: Not wishing to leave anything to luck, certain schools offer graduate degrees to selected agency administrators. Not surprisingly, these administrators make sure that their agencies provide uninterrupted funding for the research projects of their academic advisors. Who said that "ivory tower" academics lack street-smartness?

Hard working yet unfairly treated young researchers, who have the misfortune to build their careers during this sad phase of civilization, may find some consolation in sharing Mary Wollstonecraft's complaint: "The neglected education of my fellow-creatures is the grand source of the misery I deplore" (Wollstonecraft 1792). Without any doubt, in the name of the spirit of the times, the decadent elites have become a major pollutant of people's minds, souls, and imagination.

1.8.5.2 Favoring Technicians over Thinkers

By now, it has become clear that two key elements of the crisis in research are that for several decades: (*a*) research grants have been largely used to promote an entrepreneurial system that disproportionally favors technicians rather than *thinkers*; and, what is even worse, (*b*) huge amounts of government funds have been wasted to finance all kinds of causes that are completely alien to research. A system that is dominated by technicians is characterized by its lack of critical thinking, creativity, innovation, deeper meaning, and purpose. After several years of study, what many doctoral students take with them is merely a *monologic* sort of training (e.g., to operate a laboratory equipment, or to use a set of computational techniques) together with an uncompromising (and sometimes self-destructive) attitude that favors their trade. But they do not know much about the basic science underlying the functioning of the equipment, they have not learnt how to think with concepts or how to reason under conditions of in situ uncertainty, and they do not possess the human communication skills to collaborate on equal grounds with their colleagues from different disciplines. These students never undergo the crucial psychological transition from a state of being trained on what is already known to a state of individually discovering things that were not previously known. Once they get away from the monologic kind of problems that succumb to a few rules and tricks, their techniques are proven inadequate and may in fact burden them.

At the same time, large proportions of supposedly research funds are channeled to all kinds of projects that have nothing to do with real research or the study of important in situ problems. These projects aim at promoting dubious agendas, such as to facilitate political favors, fund business interests, subsidize services and products, and the like. As Gina Kolata (2009) reports, "Among the recent research grants awarded by the National Cancer Institute is one for a study asking whether people who are especially responsive to good-tasting food have the most difficulty staying on a diet. Another study will assess a Web-based program that encourages families to choose more healthful foods." In this way, valuable research funds are wasted as a result of a series of blatantly unfair and "politically correct" policies.

Well-meant people have made suggestions seeking to improve the sad state of affairs, and relieve the funding agencies from clerkdom's "deadly embrace." It has been argued with good reason that the evaluation of a research project should be based not on its sheer production (which is merely the outcome of increased resource consumption), but rather on its high productivity (assessed in terms of the "production/resources" ratio, i.e. producing the most from the least). One wonders how many of the funding agencies currently follow the former and how many follow the latter project evaluation model, and whether this has made any difference in the optimal use of the available funds.

Genuine urge for research has little to do with monetary rewards: No one should do research, unless one finds it impossible not to do research. In fact, there is sufficient evidence that in certain research areas more substantial progress would have been achieved if not large amounts of money was at stake. If monetary interests did not impose such a suffocating control on almost every aspect of scientific research, bright individuals might have more freedom to express their creativity and pursue innovative ideas. The following cases are typical: (*a*) Bright young scientists are obliged to design their research plans within the restrictive boundaries defined by the elites that control funding.[87] "He [Dr. Otis W. Brawley, chief medical officer at the cancer society] added that the problem of getting money for imaginative but chancy proposals had worsened in recent years. That makes many researchers, who need grants not just to run their labs but also sometimes to keep their faculty positions, even more cautious in the grant proposals they submit" (Kolata 2009). (*b*) Under the influence of the pseudo-practical mindset of many research funding agencies, investigators are compelled to provide solutions to poorly understood problems, simply because this is taken as evidence that they are being methodical and practical, even if the solutions are overly simplistic and unreasonable, and soon turn out to be incorrect. "I do not know," "the matter requires more study," or "this problem is unsolvable under the current conditions" are perfectly reasonable statements in research and in problem-solving, whereas the simplistic answers sought by the research agencies can do more harm than good, and are often worse than no answer at all. (*c*) Government laws that allow huge corporations to buy out small companies pursuing original research in order to eliminate any competition and achieve complete control of the market. Items *a* and *b* give readers a good idea of the suffocating environment within which IPS often has to operate. Those bright yet idealistic problem-solvers who trust their modeling skills but fail to appreciate the above hard realities could subject themselves (their research and career) to unpleasant surprises.

[87] Including government agencies and private industry. Typical is the case of pharmaceutical companies that invest huge amounts of money on specific drugs and then lobby against the funding of innovative research projects that could question their investment.

1.8.5.3 Ignore It at Your Peril

Alas, the flawed thinking that permeates the current time of Decadence has as a result a large proportion of government funds that go to support self-serving agendas of the ruling elites and the financial investments of large private corporations, even when this policy is clearly against the interest of science and the society at large. As many policy analysts have observed, the interests of these elites and the investments of private corporations are often different sides of the same coin.

Amidst all this mess, there is yet another side. Some people choose to simply ignore the existence of such a "dirty" world, at their own peril one might add. One of these people is the eminent mathematician and computer scientist Gregory Chaitin, who offered an "escape route" as follows: "Well, I prefer to ignore such an insignificant world and concentrate instead on the world of ideas, on the quest for understanding. Instead of looking down into the mud, how about looking up at the stars?" (Chaitin 2005: xiii). But the real tragedy is that, while it is the corrupted clerkdom that creates the "dirty" world system, even honest scientists are obliged to live and operate within this system. Nothing in the horizon, not even Chaitin's well-intended escape route, as yet provides a sustainable solution to the real problem.

1.9 About Models, Modeling, and Modelers

Assuming that the previous sections provided a realistic account of the socio-anthropological environment within which an in situ problem-solver has to operate, it is now time, once more, to turn our attention into IPS modeling matters. During the Paleolithic period (ca. 15,000–10,000 BC), the inhabitants of the *Altamira* caves created the famous cave paintings that represent the hunting of animals on which they fed. The representations evoke a complex relationship between the creators and their creations with regard to the represented reality (Mioduser 2005). It has been hypothesized that people created these representations of reality because of their belief in the power inherent in them to influence aspects of that reality (Fisher 1963). In contemporary terms, these paintings could be considered the oldest known *models* of aspects of reality that were vital to the lives of the people who created them. This being a sufficiently motivating start, the remainder of the chapter will attempt a review of topics related to models, modeling, and modelers. As will become evident, this trinity is characterized by a number of key elements at work, including the object to be modeled, the agent who attempts the modeling, as well as the modeling process itself.

1.9.1 Real-World and Mental Processing

Generally speaking, a *model* is a representation of certain aspects of the real-world that is created using conceptual, computational, observational, and experimental means. *Modeling* is a mental process that helps agents build models to make sense of experience by properly merging qualitative elements (intuition, insight) with quantitative descriptions (analytics, computations). Science's prime focus is the construction of increasingly improved models of various kinds and origins. Qualitative description can provide significant understanding that needs to be supported by the rigor of quantitative description to prevent bending the meaning of the words and conceptual relations. Hence, the methods of an effective IPS should be presented both in a mathematical fashion and in the comprehensive form in which they are used in real-world studies.

1.9.1.1 The Anthropocentric Factor

In Section 1.7, we saw that measurement and observation possess distinct technical and epistemic features. Likewise, modeling is an *anthropocentric* process in the manner that agents and their environment play a central role in the scheme of things. For example, an agent's solution to a real-world problem, the structure of the thinking mode that led to this solution, and the utility of the solution are all determined and interpreted to a large extent by the agent's general state of mind. This state is deeply influenced by both epistemic factors (agent's values, presuppositions, and experiences) and physical factors (underlying mechanisms, neural processes, and functions of the agent's brain).

Henri Poincaré (1963: 14) carefully emphasized the anthropocentric aspects of physical laws: "What can have laws is simply the more or less distorted image which the scientists make of it." His view was echoed in Paul Teller's relevant comment: "Laws are not eternal truths to be used only as premises in deductions. Instead, they are like basic dress patterns, to be tailored to suit the idiosyncrasies of the different customers" (Teller 1995: 5). The meaning of all this is that the brain serves as the appropriate medium with the ability to assume, hold, and deploy the conceptual creations we usually call models. That is, a model is the brain's way of making sense of the world, which happens to be its original and primary activity. In this regard, a major anthropocentric issue is the role of (immaterial) mind and its relationship to the (material) brain.

1.9.1.2 The Brain–Mind Debate

A few millennia ago, Aristotle made a now famous suggestion that turned out to play a pivotal role in the "brain–mind" debate for thousands of years: "Seeing is an act of the eye, but understanding is not an act of the brain. It is an act of our mind, an immaterial element in our makeup that may be related to, but is distinct from, the brain as a material organ." Since the time of Aristotle, the "brain–mind" debate has been at the center of many important developments as well as controversies in philosophy and neurobiological sciences.

It is safe to say that different individuals have different mental models of the world and its workings. On the basis of the knowledge available to a human agent, the agent gains an understanding of the world and uses it to reason accordingly about the world and its functions. In this remarkable symbiosis, it is not necessarily the physical world that determines the evolution of ideas. Often, it is the ideas that generate scientific and technological development. Much has been said of an agent's ability to build sophisticated mental models of the surrounding environment and then respond to these models rather than directly to the environment. Neuropsychological research shows that there are several model development stages, each one of which takes place around a particular age in the agent's life (Chapter 3). For evolutionary epistemology, a salient aspect of modeling is exactly how key mind functions (e.g., consciousness) relate to the physical world. IPS based on the adequate understanding and processing of reliable knowledge should account for the fact that empirical evidence obtained by humans requires the proper collaboration of mental functions and physical means of perception. This is not always a trivial matter. A rather extreme yet illustrative case of inadequate mental–physical association is the neurological disorder of visual agnosia (Farah 1990): the eyes (perception means) work, but the agent cannot see because the brain has not learnt (via the appropriate mental functions) to process visual information provided by the eyes. Only after intense training, the eyes and the brain may learn to collaborate, to a certain extent, so that the agent can acquire meaningful information.

1.9.2 The Language of Nature

It is widely admitted that *mathematics* is the primary modeling tool of science, i.e. a model is usually formed in mathematical terms. Mathematical modeling has been very successful as a scientific tool to the point that Galileo Galilei called it "the language of Nature." In a similar spirit, Eugene Wigner said: "Although mathematics originates in the human mind, it has been unreasonably effective in describing the non-human world. This is a wonderful gift that we neither understand nor deserve." In his address to the Prussian Academy of Science (Berlin, Germany; January 27, 1921), Einstein noticed: "At this point an enigma presents itself which in all ages has agitated inquiring minds. How can it be that mathematics, being after all a product of human thought that is independent of experience, is so admirably appropriate to the objects of reality? Is human reason, then, without experience, merely by taking thought, able to fathom the properties of real things? In my opinion the answer to this question is briefly this: as far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality."

1.9.2.1 The Relationship Between Mental Constructs and Reality

Underlying Einstein's comment is his appreciation of the key relationship between mental constructs (mathematical models) and reality, and the crucial role of uncertainty in this relationship when mathematical models are implemented in situ. The preceding analysis implies that if an adequate bridge could be established between mental and natural states, it would lead (*inter alia*) to the development of an innovative approach for constructing mathematical models of natural systems. The development of such an approach would account for the possibilities that these models may not be purely objective entities but rather the creation of mental processes. As such, the models provide incomplete representations of the natural states since they apply only to certain aspects of the real-world. The solution of these models in terms of IPS should not be merely a technical exercise but the outcome of conscious mind–environment interactions (in which case, it is worth revisiting the meaning of the term "solution;" Section 2.3.2).

This is mind-provoking stuff, in which case one needs to set forth as precisely as possible the reference frame of one's modeling effort. Effective modeling relates to natural phenomena by means of description, prediction, and explanation. These are well-established features of any real-world modeling effort: *Description* (in the form of data tabulation, calculation of various types of dependence, and visualization schemes) arranges and evaluates information in a way that is easier to comprehend and use. *Prediction* (involving space–time attribute maps and substantive statements about unexplored domains and future events) produces new knowledge. *Explanation* (in the form of evidentially supported relations between concepts) offers an understanding of the original phenomenon and related problems, and it can even offer inspiration and suggest new analogies for unrelated problems. It is, also, common practice in science that the mathematical form of a model is abstracted out and then applied *analogically* to different disciplines. As an abstract representation of reality, the same model formulation may apply to a variety of phenomena in different scientific disciplines (the same differential equation model, e.g., is used to represent phenomena in fluid mechanics, electromagnetism, and epidemiology). The readers may find it remarkable that modern models have been linked to Plato's world of *Forms* accessible only via the agent's mental reflections (Section 2.2.4). And even if a mathematical model cannot be seen as an element of the celebrated Platonic World, its analogical power can be extremely useful in many kinds of scientific investigations. In view of this realization, when phenomena in different disciplines share the same mathematical formulation, findings in one discipline can be properly translated to the other, thus leading to fruitful hypotheses, innovative analyses, and unexpected results. For example, after he discovered the similarity between the structure of the nucleus formed by nucleons and that of a drop of water formed by molecules, Bohr was able to translate the known facts of evaporation into those of radioactive disintegration, and the conditions under which the droplet divides in two anticipated those under which fission occurs. From this work, the atomic bomb was to emerge, eventually (Dupuy 2000).

1.9.2.2 Mathematics of IPS

The foregoing considerations bring to the fore the need to elucidate what is the essence of mathematical modeling, and how it should be used meaningfully and efficiently in IPS. It is worth noticing that the common conception of "applied mathematician" (i.e., one who almost mechanically approximates complex analytical expressions in terms of computational schemes and then solves them numerically) is not always adequate. It rather gives the impression of a "brute force" conception that could lead to the creation of what software engineers call "kludge" (i.e., computer codes written without foresight that wind up full of burdensome and useless complexity, often to the point of becoming incomprehensible even to those who wrote them). An applied mathematician's role better be one that relies on physical insight and interpretive reasoning to understand the pattern underlying the analytical expressions so that they can be reduced to simpler ones, free of any apparent complications, and then proceed with the solution of the simpler yet equally meaningful expression. In the IPS context, this role implies a series of tasks. For example, in order to check the numerical methods and understand their significance, an applied mathematician may need to find approximate analytical solutions in various limiting cases. On a relevant note, so important a role does physical insight based on deep conceptual understanding play in guiding theorists that those individuals with a strong track record of being able to correctly anticipate complex results based on their instincts gain a guru-like status in their disciplines. Let us close this topic with the historical example of Karl Friedrich Gauss who had confessed that, " I have had my solutions for a long time, but I do not know how I am to arrive at them" (Christian, 2009: 166).

With the above considerations in mind, one must examine with due care the ways in which mathematics is applicable in the empirical world, including theoretical and practical matters. Sound IPS modeling involves basic considerations about: (*a*) The meaning of mathematical symbols and terms; it is one thing to claim to know the meaning of the symbol *X* (symbolizing, say, water) and another thing to state a criterion of *X* (e.g., a set of physical requirements that the symbol must satisfy or link to). (*b*) The logical form by means of which mathematics is used in reasoning; in mathematics the numerical values (say, nine) are used as nouns, but in empirical investigations they function as adjectives (e.g., nine boxes). (*c*) Its methodological underpinnings; the numerical values of mathematical manipulations do not refer to empirical entities but rather to empirical concepts used to describe the entities. These issues play a key role in IPS, which is why they are revisited in various parts of the book. Many thinkers believe that mathematical modeling, at its best, combines an element of *beauty* and one of *convenience*: modeling embeds beauty in a rich tapestry of technical rigor, innovative conceptualization, and realistic representation of a natural phenomenon. For George Steiner (1998), beauty and convenience serve as internal criteria in creating the equations that describe aspects of Nature.

1.9.3 Reality Does Not Have to Be Beautiful, but Models Do

One can find many eminent theorists who subscribe to the above doctrine (and so would do some of the readers, at least). As a matter of fact, the connections between science and *art*[88] are multidimensional and multithematical, spanning many different areas of human creativity and innovation. In the broadest sense, art embraces creative fields like literature, poetry, painting, sculpture, architecture, design, music, dance, theater, and cinema. Art is a human creation generated of one's own impulse, and is intended to stimulate an aesthetic experience. In the words of Pablo Picasso: "We all know that art is not truth. It is a lie that teaches us how to comprehend the truth, or at least that truth we human beings are capable of comprehending."

We start our discussion of these artistic fields in a modeling milieu, by bringing to the readers' attention the intriguing fact that creative science modeling and art can mutually benefit from their interaction. According to Arthur Miller (2005: 44): "At the moment of creative insight, boundaries dissolve between disciplines and both artists and scientists search for new modes of aesthetics. That was certainly the case with Albert Einstein and Pablo Picasso. They were both trying to understand the true properties of space, and to reconcile them with how space is seen by different observers. Einstein discovered relativity and Picasso discovered cubism almost simultaneously ... Cubism directly helped Niels Bohr discover the principle of complementarity in quantum theory." Much has been said of the worldview in which truth and beauty go hand in hand, in a way that the latter offers testimony to the reality of the former. Those inspired by beauty have a deep conviction that the world is ordered by laws of aesthetically pleasing symmetry and powerful simplicity. This was the case of Albert Einstein, Niels Bohr, John Dewey, Subrahmanyan Chandrasekhar, and Paul Dirac. John Dewey believed that art should be encouraged because it stimulates imaginative solutions to its own unique problems, some of which, if considered in an appropriate framework, could help generate innovative solutions to real-world problems. The close interaction between beauty and mathematical modeling finds also attestation in the words of Paul Dirac: "It is more important to have beauty in one's equations than to have them fit the experiment." The message here is that reality does not have to be beautiful, but the models of reality do. Next, we focus on certain connections between modeling and art (in its various forms). One of the strongest links between the two is their mutual use of metaphor (Section 2.4.2) in a variety of ingenious and innovative ways.

1.9.3.1 Modeling as Theatrical Performing

Since the times of the ancient Greek masters Euripedes, Sophocles, and Aristophanes, the world of *theatrical performing* – with its stage, costumes, metaphors, roles, and personas – has been one of the most insightful ways of expressing human concerns and views about real-world affairs. In her intriguing study of the nature of artistic performance, Dzifa Benson (2006) focused on the fictional character *Jacques*

[88] The word "Art" comes from the Latin *ars*, meaning skill.

(the hero of William Shakespeare's *As You Like It*). At a stage of introspection, Jacques says:

All the world's stage
And all the men and women merely players
They have their exits and their entrances
And one man in his time plays many parts...

In this passage, Shakespeare uses a metaphor, the "world" is transformed into "stage," in which case all the attributes of the latter are applied back to the former. In Shakespeare's time, theatrical performance was a powerful expression of tradition and wisdom. With its irresistible appeal, theatrical performance remains a creative process of discovery and transformation in our time. "When I am performing," Benson (2006: 15) confesses, "I want to find new ways, new language, verbal and non-verbal to express universal truths. I want to push the challenge of understanding deeper . . . I want to punch through the chest of the obvious to get to the blood-soaked, beating heart of things: to hold the core of the truth up still pumping with life for all my audience to see."

Theatrical performing has much in common with modeling in that they both involve performers (artists and modelers, respectively) and their objects (real or imaginary situations), make use of metaphors, and are basically a transformation of ideas and vision into outward action. Just as performing does, modeling seeks to find novel ways to express findings about an agent's inner and outer worlds; to translate ideas into actions and beliefs into knowledge; and to do all of the above while emphasizing substance over style. Like performing, modeling is part of the creative process. It places due emphasis on understanding this process and not just its end result, the so-called products (e.g., problem–solutions and actions). In this way, the investigator recognizes and experiences the mental states that led to the generation of the products and learns how these products came to be.

1.9.3.2 Poetry's Link to Modeling

Poetry is another creative art with intriguing links to modeling. Referring to quantum mechanics models, Niels Bohr remarked that, "When it comes to atoms, language can be used only as in poetry. The poet, too, is not nearly so concerned with describing facts as with creating images and establishing mental connections." A similar link between poetry and mathematics is found in the comment of Gregory Chaitin (2005: xii): "A mathematician who is not something of a poet will never be a good mathematician." If mathematics is poetry to one who understands, it is not surprising that the theorists of science are often seen as the poets of Nature. According to Novalis,[89] by speaking *one* language, scientists and poets have always

[89] Author and philosopher of early German Romanticism, whose real name was Georg Philipp Friedrich Freiherr von Hardenberg.

shown themselves to be *one* people. Referring to Paul Dirac, Graham Farmelo (2002) recalls that Dirac once said that a good deal of his work consisted of simply examining mathematical quantities that physicists use and trying to fit them together in an interesting way, regardless of any application the work may have. This is a bit like trying to write a poem by assembling the words in an attractive order and then seeing if it reads as poetry. "Like great poems, Dirac's papers reward repeated reading" (Farmelo 2009: 50).

Poetry exhibits a creative imagination that is often ahead of its day. Some basic features of the twentieth century scientific concept of *space–time* are traced in the eighteenth and nineteenth century literature. In his 1848 essay *Eureka*, Edgar Allan Poe wrote that, "space and duration are one," suggesting space and time to be different perceptions of the same entity (this conclusion was drawn by Poe after a lengthy reasoning that did not use any mathematics). The eighteenth century British poet and painter William Blake[90] suggested that time and space have no absolute existence but are twin aspects of Eternity as perceived by our limited senses. The most powerful link between modeling and poetry is the extensive use of metaphors by both. In Section 1.8.1, we referred to Feynman's study of the relations between different sciences using the "glass of wine" metaphor. Section 2.4.2 addresses in a more systematic manner the use of metaphors in scientific modeling. The great metaphorical power of poetry offers the means for representing and communicating central elements of human inquiry. Section 1.1.2 discussed the powerful metaphorical structure of Parmenides' Poem *On Nature*. And as we will see in Section 3.10.2, Man's quest of *Truth* is described in Cavafy's poetry by the fascinating metaphor of Odysseus's journey to the island of Ithaca.

1.9.3.3 Exploring Art–Science–Philosophy Interactions

Can the mind express itself in a speculative and artistic form? In ancient China, to be a scholar meant to immerse oneself in the four arts: *qin* (musical instruments), *qi* (board games), *shu* (calligraphy), and *hu*a (painting). Accordingly, the Chinese ideals of an educated Man are demonstrated by one's ability in creation, expression, reason, and dexterity. These ideals rated highly in ancient China and so do in modern times too, where they are conveyed in ways that involve the appreciation of science and its artistic connections. There is considerable evidence of the interaction between art, philosophy and science (McDowall, 1918; Read, 1955). In a previous section we pointed out the intellectual connections between Picasso's cubism and the physical theories of Einstein and Bohr. It is well known that Descartes' philosophy had an immense effect on the French literature of his age. Hegel famously remarked that philosophy paints her "grey-in-grey" only when some living form of activity has grown old. In recent times, some scholars argue that the term

[90] Largely unrecognized during his lifetime, Blake's work is today considered seminal and significant in the history of both poetry and the visual arts.

"postmodern" originally appeared in the title of Charles Jencks' influential treatise *The Language of Post-Modern Architecture* in 1975, and was being bandied about in the 1960s in connection with contemporary dance and literature. "Jencks described postmodern architecture as a rejection of the functionalism and formalism of modernist architecture, and the substitution in its place of pluralism, ambiguity and pastiche in styles. This is the architectural analogue of the philosophical rejection of foundations and absolute truth" (Grayling, 2010: 390–391).

During the last decades, several scientists and artists worldwide have started exploring in a systematic manner the conditions under which the artistic thinking style could be properly incorporated in scientific investigations. As Tsung Dao Lee puts it, "Both, science and art are not separated from each other. There is even a similarity between them as they help us observe Nature. With the help of science we can find out routines of Nature. On the other hand, by means of art we can describe the emotions of Nature." A number of research centers and laboratories worldwide focus on art–science interactions (Gorman and Jesani 2008): *Le Laboratoire* in Paris (France); the *BeiLAB* in Beijing (China); the *CEMA* in Bangalore (India); the *foam* in Brussels (Belgium); and the *UCLA Art|Sci Center and Lab* in Los Angeles (U.S.A.). These activities offer considerable hope that art and science would be able to integrate their thought processes in a systematic manner capable of generating creative approaches to solving important real-world problems. The above also demonstrate how wrong some radical postmodernists can be when they suggest to dissociate art from science. This is the case of feminist geographers like Mei-Po Kwan who seems to consider it an achievement that "Through this abstract and nonrepresentational GIS art practice, GIS is momentarily dissociated from any precepts of science…" (Kwan 2007: 28). Remarkably, feminists' geographers do not seem to be concerned that their opposition to the scientific consideration of GIS directly contradicts the efforts of certain distinguished geographers (Goodchild 2006) to change the meaning of the "S" word in GIS from "systems" to "science." Under the circumstances, some wonder whether assigning the meaning "schism" to the word "S" may be more representative of the situation.

There is, however, one legitimate concern about what kind of art one refers to. What could be reasonably called a characteristic case of the architectural crimes of modernism is the demolition of the monumental old Penn Station in New York City, and its subsequent replacement with an uninspiring modern design. Just as in art, in scientific inquiry too it is not always true that the modern is an improved substitute of the classic. The almost uncontrollable desire to create things that appear modern is by no means a satisfactory motivation for change (and it does not justify the increasingly valuable funds that change requires), if this desire is not combined with a deep appreciation of the relative merits of the classic, and the actual improvements (aesthetic, intellectual, and cultural) eventually brought by the proposed change are not adequately substantiated and communicated. Representative in this respect is the case of the *Futurism* movement that expresses a passionate loathing of tradition and everything that is old, while it uncritically admires youth, speed, power, and technology (Section 1.10.3).

1.10 Reinventing the University and a New Enlightenment

I hope the readers agree that it is appropriate to revisit the subject of higher education (Section 1.5) in the light of the ideas and developments discussed in Sections 1.6–1.9. Indeed, the significant issues and concerns examined in these sections can have a huge impact in the context of an ongoing movement that seeks to put an end to the PCU mindset, which has caused enormous damage to the students' education and the society at large, and proceed with a discussion of the major undertaking of reinventing the notion of the university and its pivotal role in the education of problem-solvers under conditions of real-world uncertainty.

1.10.1 PCU's Focus on Lower Needs, and the Challenges of Twenty-First Century

As we saw in Section 1.5, the current PCU environment emphasizes the satisfaction of the lower needs of students, such as physiological comfort, meaningless pleasures, and material consumerism, whereas it pays no attention to the students' higher needs, such as the ability for abstract thinking, comprehension and insight, and the search for identity, self-respect, and purpose in life. Many students view corporations as role models because only they seem capable of fully insulating themselves from the effects of their own mistakes, failures and mischiefs. As a result, young people come to live and operate in a society where the shadow epistemology and the corporate logic have insinuated themselves in every area of their lives (Rushkoff 2010). The above are the natural consequences of the major twofold change brought by the PCU mindset: (*a*) the professoriat has been proletarianized as a body whose uninspiring role is determined solely on the basis of market rules, and politically correct directives; and (*b*) administrators rather than scholars are the real bosses on campus, those who assure the assimilation of the university into an all-encompassing corporatism. Even elite universities are not totally immune to the PCU influence. According to Hedges (2009: 89), "Harvard, Yale, Princeton, Stanford, Oxford, Cambridge, the University of Toronto, and the Paris Institute of Political Studies, along with most elite schools, do only a mediocre job of teaching students to question and think... Responsibility for the collapse of the global economy runs in a direct line from the manicured quadrangles and academic halls in Cambridge, New Haven, Toronto, and Paris to the financial and political centers of power. The elite universities disdain honest intellectual inquiry... They organize learning around minutely specialized disciplines, narrow answers, and rigid structures designed to produce such answers."

What characterizes a typical PCU curriculum today is a notable lack of *intellectual challenge* or *inspiration* for the student who is the ultimate loser in more than one ways. Busily transmogrifying the university into a bureaucratically organized and consumer-oriented corporation, the campus clerkdom fails to understand that it is theoretical thinking that has led to some of the most valuable discoveries in human history. The readers should not forget, e.g., that when some pioneers were dreaming of flying, the clerkdom of their times was dismissing them as useless intellectuals pursuing the impossible. Moreover, in its current form the university is unable to prepare students for the most critical element of twenty-first century life: The unknown but potentially catastrophic consequences worldwide of the anticipated slowing down of material growth, and the restrictions on the *status quo* (western world standards of living, and the widespread consumption culture) imposed by climate change, economic globalization, and international instability. It is highly uncertain that crucial issues emerging worldwide as a result of these restrictions can be always resolved with democratic procedures, and a generation of inadequately educated people will make things much worse.

1.10.2 A Student-Mission, Not a Student-Customer

Therefore, reinventing the notion of the university is a major affair with many important components and far-reaching consequences. There is not sufficient space in this book to discuss the matter of higher education in due detail – other colleagues have already done a better job in this respect. The list includes, but is not limited to, the remarkable works of Slaughter and Leslie (1997), Readings (1996), Amaral et al. (2003), Edmundson (2004), Engwall (2007), Nybom (2007), Bauerlein (2008), and Jacoby (2009). Nevertheless, I hope the readers will tolerate a few brief comments. Above all, a reinvented university must replace the failed notion of a "student-customer" with the concept of a "student-mission." Each student should be considered as a mission by the professor and the scholar on campus, in a way that an intellectual link is established between the two who consider themselves members of a community. Professors' duties include helping students become highly educated professionals, cultivated individuals, and citizens-critical thinkers. Students should view "life on campus" as a process of higher learning, self-discovery, and self-respect. Due to the increasing complexity of modern societies at many inter-connected levels (e.g., family, education, occupation, finances, health support, politics, and legal structure), students must possess considerable integrative cognition and reasoning abilities, being able to understand and synthesize dissimilar conceptual systems and different thinking styles. In sum, higher education should involve a transformative process in which both the teacher and the student are transformed, and in these transformations lie both the authority and the responsibility of the teacher.

This "teacher–student" link presupposes that the central figure of the university is the professor (who ought to be a respected educator and a devoted scholar), and not the administrators (whose main goal so far has been to establish a corporate atmosphere in order to facilitate their control and aggrandize their own positions). The university should move from the suffocating curriculum of mechanical and dry overspecialization to a more integrated curriculum based on the living experience of knowledge synthesis. This is a curriculum that combines academic inquiry and practical experience in a sophisticated process of critical thinking and creative expression, rather than expect students to memorize the equivalent of phone directories. A curriculum that assures that in the process of pursuing knowledge and understanding the students are moved. The pleasure of understanding enhances, refines, and guides the students' sensory engagement with the world. Students should be taught that great geniuses, like Leonardo da Vinci, Shen Kuo, and Johann Wolfgang von Goethe, were well versed in science as well as in art. Students should *learn how to learn*, how to employ thought experiments and argument dissections to further explain their ideas, and how to use what they are taught to form a better worldview. University education should inspire students to search for their identity and purpose in life, encourage them to take risks, and prepare them to deal with the unknown and the constantly changing conditions of the world. Students should appreciate the Latin epigram, *Cave ab homine unius libri* (beware of anyone who has just one book). This means, e.g., that science, mathematics, business, and engineering students would have to widen their education with courses and projects in other disciplines, such as philosophy, literature, history, and art. At this point, one could bring to the attention of the PCU devotees an interesting comment made by a modern Chinese politician concerning interdisciplinary education and its positive effects. Discussing China's new policies to bust innovation and creativity, the vice minister of education Wu Qidi predicted that, "I believe that arts will play an important role. It is even more important to have an integration of arts and science so people will have the creative and independent thinking" (Friedman 2007: 367). It is expected with good reason that an interdisciplinary curriculum will help students become not only better professionals and effective problem-solvers, but also to live a more balanced and meaningful life, and become better citizens, parents, spouses, and friends.

1.10.3 A New Enlightenment

It is rather a matter of elementary logic that since the complexity of the society increases, the sophistication of education needs to improve. For most people, the current model in which a period of training is followed by a life of work needs to be replaced by the model of lifetime education, conscious awareness, and integration. This being the case, we may be on the verge of the greatest revolution humanity has ever experienced: The revolution of consciousness and the emergence of a *new Enlightenment*. This will imply a new way of looking at reality, a deeper appreciation of human values and principles, an enhanced capacity for creative thinking, more advanced modes of experience and cognition, and the development of improved IPS frameworks based on the appropriate balance between concrete and abstract thinking.

The New Enlightenment University (NEU) should be ready to confront the chameleonic metamorphoses of the PCU system. Among them is the futuristic so-called Good Enough Revolution (GER) aiming at replacing the real university with some sort of virtual training. According to the futurist Thomas Frey, one of GER's loudest advocates, while most universities are striving to "be the best," most students and their parents are opting for a solution that is "good enough," and "Corporations will quickly invent a faster, better, cheaper model for delivering college education" (Frey 2009). Apparently, GER's vision is to further lower the educational standards, and allow corporatism to continue its catastrophic influence on higher education. The GER value system is revealed in Frey's own words: "While department heads in colleges are off studying the mating rituals of Komodo Dragons in Indonesia, corporate managers are working day and night, ruthlessly focused on opening new markets and uncovering new revenue streams." An interesting comparison indeed. If history teaches us anything, one can imagine Charles Darwin in the place of the college head, and nineteenth century British traders in China opening new opium markets in the place of Frey's corporate managers, to get a good idea of what the GER values and priorities are about.

The university stakeholders in the state and the society ought to provide an appreciative, stable, and creative environment for universities of the new Enlightenment to flourish, as well as to establish a rigorous and credible accountability process that has high-quality education and research standards, and it relies on disciplinary experts, rather than on the opportunistic PCU policies that use the university primarily for political gains and agenda-driven purposes. For many years, these PCU policies have dramatically reduced the quality of education and research, and have endangered the stability and prosperity of the society at large. While in the PCU system the students evolve from subjects to consumers, the NEU should help them evolve from subjects to citizens. In direct opposition to the illusion that all is needed is to merely transmogrify university into a corporate operation that generates financial profit, the university's main asset is its hard-gained reputation that enables it to accomplish its crucial tasks of higher education and quality research. It may not be enough for the NEU to suggest replacing the purely monetary standards of the PCU model with a robust value system. This would be inadequate in itself, because the meaning of real values has been corrupted in the current commodified society. Without a reassessment of what human values actually are, there cannot be a substantive and sustainable societal reform and this includes real-world problem-solving. For such a development to occur there must be a change in how young students see the world working, and this is, to a large extend, the mission of the NEU. To succeed in its mission, university relies on its long survival record. On the contrary, like most corporations, a "university turn in to corporation" will probably be a short-term affair. This does not concern the cynical managers, since they can always abandon university for another more profitable investment (say, lingerie factories using third-world slave labor), but it is a catastrophic possibility for humanity, nevertheless.

Surely, the reinvented university of the new Enlightenment need not alienate itself from the business world (in its broad scope and constructive role in society, and not the human exploitation, marked avaricious sense adapted by corporatism). It is probably valid that the interface between the university products and the business needs is in a state of flux. In this respect, the rules governing the "university–business" relationship should be revised to allow a meaningful synthesis of the necessarily long-term goals of higher education and the short-term goals of business. And, of course, the synthesis should by no means involve the kind of corporations that Michael Hudson (2008) has characterized as a kleptocratic class that took over the American economy and got away with "the largest and most inequitable transfer of wealth since the land giveaways to the railroad barons during the Civil War era." Accordingly, the reinvented university should hold strong to its values and ideals, and not give into the pressure of the World Bank or any similarly esoteric organization with self-serving agendas and suspicious motivations, as happened in the 1980s and 90s (Section 1.5). The university must become again a democratic public sphere. Educators and researchers should be able to ask the uncomfortable questions whenever this is necessary, without the risk of prosecution. Professors should never again have the fate of Henry A. Giroux, the Waterbury Chair Professor at Penn State University (Hedges 2009: 90–91): "He [Giroux] has long been one of the most prescient and vocal critics of the corporate state and the systemic destruction of American education. He was driven, because of his work, to the margins of academia in the U.S... Giroux, who wrote *The University in Chains: Confronting the Military-Industrial-Academic Complex*, left in 2004 for Canada."[91] Sadly, Giroux's faith was shared by many other distinguished academics: "Many disappeared into discourses that threatened no one, some simply were too scared to raise critical issues in their classrooms for fear of being fired, and many simply no longer had the conviction to uphold the university as a democratic public sphere." A phase of Decadence, indeed, bestowed to the world by the PCU model and its ruthless devotees.

1.11 Nonegocentric Individualism in IPS

It is time to take stock. This introductory chapter sets the scene so that the readers can see what kind of a project I have in mind. Various intriguing aspects of human inquiry were discussed in this first chapter of the book, including my own views and even prejudices about the matter, and some critical questions were raised accordingly.

[91] The characterization "Military-Industrial-Academic Complex" was used by President Dwight D. Eisenhower who tried to warn people about the dark future.

1.11.1 Critical Questions and the Emergence of Epibraimatics

Critical questions concerning human inquire, in general, and IPS, in particular, justifiably included the following: What should be the role of higher education in preparing students for the challenges of the twenty-first century? What can be known in mathematics and how it possibly relates to or even contrasts with what scientists claim to know about physical reality? What is the nature and function of scientific theories and laws in the IPS setting? Is it possible to develop an IPS framework that reaches a compromise between the technically sophisticated but idealistic mathematics and the physically meaningful epistemology of complex in situ systems? What should be the role of brain functions and neuropsychological patterns shaped during many years of evolutionary pressures in the development of such a framework? When is logic theory sufficient and when are substantive logic-external considerations needed? What are the societal restrictions on IPS (including the priority of the problems to be studied, the choice of the solutions, and the actions that follow)?[92] How to eliminate the negative effects of shadow epistemology on scientific research and development?

The above questions "put the finger into the nail-mark," so to speak, and directly recognize the need to develop a broad IPS framework that takes into consideration a number of problem- and agent-related elements in a systematic and integrative manner. Surely, the considerable goals of such a project cannot be accomplished within the boundaries of a single book. Nevertheless, the book's intended contribution is to critically review the state of affairs in a time of Decadence, and examine the possibility that an IPS approach could be developed in the context of what one would term Epibraimatics; i.e., a mental construction that involves a rigorous problem–solution methodology that views the subject (scientist) and the object (problem) as an integrated whole; recognizes that, despite its great usefulness, deterministic mathematics cannot be comprehensive enough to express fully the everyday notion of truth;[93] and supports the perspective that quantitative modeling needs more avant-garde ideas and mental finesse that synthesizes form and content.

1.11.2 Egocentric Individualism and Its Problems

Egocentric individualism is a prime characteristic of modern culture that defines individual freedom as the state of dynamic personalization in which one gets

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[92] Sooner rather than later, a problem-solver is confronted with the great disease of western societies (and not only): a majority of people believe that there are really no serious problems in life that are worth-solving except their own financial well-being (i.e., all other kinds of problems can be resolved in financial terms). As a result, no restraints of any sort (moral, spiritual or intellectual) can slow down the frantic race for material gains, excessive consumption, and the satisfaction of lower needs.

[93] In linguistic terms, no amount of syntax can entirely eliminate semantics.

whatever one wants when one wants, or considers reality on the basis of a self-serving viewpoint according to which truth is whatever serves the interests of a specific group of individuals. Modern communities that are grounded on egocentric self-preservation are culturally impoverished. Egocentric individualism characterizes people who are indifferent to the views and needs of others, and rarely admit the limitations of their own viewpoints. As such, egocentric individualism can have severe consequences that include narrow mindedness, injustice, manipulation of facts, and even self-deception.

Sadly, egocentrism pervades many components of the society, from science to politics. In politics, egocentrism can prevent people from appreciating crucial events, even when these events hit them in the face. Referring to a decadent period of UK politics, Peter Oborne (2005: 26–27) wrote: "The evidence was accessible to me – just as it was available to all of us lobby reporters, and everyone else. But we didn't want to look, and even if we had looked, no one would have wanted to know about it." In science, it is not unusual that individuals interpret facts in an egocentric manner, use knowledge in a self-centered fashion, and evaluate theories and models in an agenda-driven way. A typical case of egocentrism is the claim of certain epidemiologists that composite space–time changes are insignificant features of the quantitative analysis of an epidemic – which is probably why the reading of mainstream epidemiology books (e.g., Rothman 2002; Savitz 2003) leaves a sense that there are holes large enough to pass the RMS Titanic through them.The neglect of key notions such as spatiotemporal continuum, causality, environmental and social context, because they lied outside the mainstream paradigm[94] contemned much of epidemiology to intellectual repetition and stagnation. The black box and risk factor epidemiology of David A. Savitz (1994) and others has "impoverished epidemiology and has constrained not only the methods that we use but also the way in which we formulate research questions and even the research questions that we ask" (Diez-Roux 2008: 230). Despite early warnings about the "emptiness" of the black box approach (Skrabanek 1994), this limited vision of epidemiology dominated the field for years: "Even in the scientific arena, epidemiology cannot provide the essential knowledge in the fields of sociology, economics, and human biology that public health leaders need" (Savitz et al. 1999). As a result, many investigators become increasingly skeptical whether "epidemiologists should essentially become data collectors for molecular biologists" (Pearson 2007: 714). Scientific egocentrism characterizes the sort of environmental contamination analysis that looks at the problem from a very narrow angle, lacking context and meaning (Gorelick 1990; Knox et al. 1993; Herfort et al. 2000; Myers 2002; Teles et al. 2006). This angle combines a neglect of fundamental developments (in both stochastic analysis and environmental science) with flawed logical reasoning and lack of deep physical understanding. Among other things, such studies profoundly underestimate the

[94] Randomized clinical trials with risk factors and disease outcomes considered in isolation, using black-box techniques, estimating "independent" associations rather than understanding causes, preoccupied with proximate risk factors etc.

importance of the porous media geometry and the unknown geomorphology features in contaminant transport; the space–time transport mechanisms are not taken into account together with various uncertainty sources; and key physical processes are neglected (e.g., chemical fingerprint studies of large contaminant plumes show an inability to take account of subsurface geochemical processes that occur naturally across space–time). Which is probably why after several decades of largely misdirected research effort contaminant transport in heterogeneous porous media is still a field characterized to a large extend by Feynman's observation, "All we know so far is what doesn't work."

Disciplinary egocentrism is at the root of many disciplines' strong tendency to develop their own hermetic jargon (Section 1.4.1). According to Henk Tennekes (2010), the term "hermetic jargon" describes "the secret language that eliminates the risk of having to discuss the foundations of one's discipline with the outside world." Technologies using a carefully crafted hermetic jargon (comprehensible only to the in-crowd) are promoted on the basis of narrowly defined gains, but when the jargon is removed, one discovers that their conceptual bases has nothing new to offer, and that they do not fit well-established results obtained thanks to the great effort of others, during long periods of time. The fashionable copula technology, e.g., has been adopted by some researchers because its language (Mikosch 2006a: 4–5) "has led them to publish papers with complicated technical assumptions, whereas the results are not new when considered in the usual language of distributions," and despite the fact that the technology does not fit the theory of stochastic processes, which is "a well established theory in which some of the finest minds of probability theory have been working for about 100 years." Last but not least, many of the incidents of Para-Oedipal act (Section 1.8.4) are direct consequences of the egocentric mindset.

Yet, one of the most remarkable and consequential examples of egocentrism is found in the economics discipline. At the top of academic economics in U.S.A. are the "Chicago School" and the "MIT School." As James K. Galbraith (2009) notices, deeply preoccupied with their status and struggle for worldwide influence and academic prestige, both schools failed miserably to respond to the greatest economic challenge of a generation. Their uncompromising self-absorbedness and egocentric mindset delusioned them into thinking they possess exclusive access to the truth, and prevented them from even considering the sound warnings of economists not belonging to the self-appointed elite. What is even worse, when proven disastrously wrong, their egocentrism prevented these schools from going through the cathartic process of self-criticism. In psychology, Ralph Ellis (1996) has suggested that ignoring the countervailing motivation toward intensification rather than conscious feeling reduction has led to an egocentric view of human nature. This, in turn, motivates a simplistic hedonism in value thinking and an atomistic-individualistic conception of society. The ultracompetitive nature of this kind of culture leads to overconcern with masks of invulnerability that prevents the dropping of superficial defenses necessary for deep and authentic relationships to mature. The intense experience of the intrinsic value of another being is required in order to combat the existential threats to the meaningfulness of life (alienation, powerlessness, and death). What all these cases of egocentrism have in common is the complete neglect of meaning in human inquiry. As noted earlier, for the clerkdom, any reference to truth and meaning is the ultimate conversation stopper. Yet, one of the most urgent needs and difficult achievements is the search for meaning and purpose in human activities. Relevant are the warnings of many scholars, including Michael Novak (2009: 12), "The experience of nothingness is now the point from which nearly every reflective man begins his adult life;" Viktor E. Frankl (2000: 112), "Man is in search of meaning . . . today his search is unsatisfied and thus constitutes the pathology of our age;" and Robert C. Solomon (1993: 28), "The 'why' has no answer and that is the singular fact that now defines our existence . . . It follows with merciless logic from our most everyday thinking."

Χαλεπά τά καλά:[95] In the Information era, it seems beyond comprehension how people can live with the delusional sense of an egocentric mindset. When research is guided by egocentrism, scientific disciplines are pushed decades backward – some disciplines already share such a demoralizing experience. In this sense, egocentrism is a major contributor to scientific Decadence. Since it is our habit to think in a literary way about scientific matters, a short of a literary science viewpoint (I use this oxymoron by design), let us conclude our brief discussion of egocentrism with the celebrated poem "Walls," by Constantine P. Cavafy (2007):

> Without consideration, without pity, without shame
> they have built great and high walls around me.
> And now I sit here and despair.
> I think of nothing else: this fate gnaws at my mind;
> for I had many things to do outside.
> Ah why did I not pay attention when they were building the walls.
> But I never heard any noise or sound of builders.
> Imperceptibly they shut me from the outside world.

The poem offers a powerful metaphor of egocentrism's grave consequences on human existence and the society at large. Isolationism is represented by the "great and high walls" that imperceptibly close a human being off from the outside world. If an agent is not careful, little by little egocentrism's walls can become the agent's natural climate.

1.11.3 Nonegocentric Individualism and King Minos' Labyrinth

In light of the above considerations, one of the main aims of the new Enlightenment would be the overcoming of excessive egocentricity, which is believed to be a key cause of contemporary problems in science, education, research, politics, and the society at large. Accordingly, Epibraimatics' prime suggestion is to replace the traditional egocentric individualism with *nonegocentric individualism*, the state of expressing one's values and purpose without being self-centered in value thinking;

[95] "Good things are difficult to attain;" Plato, *Republic* **4**: 435c.

of viewing with its distinguished individuality rather than as a unit of a large community. Admittedly, nonegocentric individualism is a tough combination that requires that a human agent be pulled out of oneself into a way of experiencing that rises above one's ego rather than expands it; to be value-sensitive (including ethics, purpose, quality, impact, and possibility); to encourage the continuous dialogue between different disciplines and fields; to install uncompromising meritocracy and put progress in human inquiry above individual gains and institutional agendas; to advance knowledge for its own sake rather than prove that one is right and the others are wrong; and to understand people not merely as psychological subjects. Nonegocentric individualism relies on epistemic synthesis, i.e. the integration of different belief systems and thinking styles that aim at a balance between divergent or even opposing proposals, to draw out and combine that which is valuable in each. The absence of epistemic synthesis is profound in disciplines with dominant egocentric characteristics. In this respect, representative are the cases of mainstream statistics (which passionately focuses on the "let the data speak" doctrine, and ignores the underlying epistemology); of neurobiology (which devotes its efforts on brain activities[96] and underestimates the relevance of mental states and behavioral patterns); and of empirical psychology (which searches for regularities in people's behavior during controlled experiments and dismisses theorizing and abstract thinking).

At the heart of Epibraimatics is the systematic development of stochastic reasoning (see Section 1.2.3, and other parts of the book). To best represent the living experience brought about by the "investigator–world" interaction, stochastic reasoning considers arguments that belong not only to language (refer to entities) but also arguments that belong to metalanguage (linked to investigator's assertions about entities). The latter arguments are not definite but rather conditioned on the available (often incomplete) knowledge. Accordingly, they involve knowledge-theoretic probabilistic descriptions of in situ phenomena in which chance and necessity constitute an integrated whole. Descriptions are subjected to context- and content-dependent mathematical representations. The foregoing accounts require that an investigator first clears up the inner essence of a problem, before attempting to derive a solution. Viewed in this milieu, the problem-solver's thinking mode should be characterized by skepticism, objectivity, an appreciation of uncertainty, and the flexibility to alter one's beliefs in the face of powerful evidence. Within the scientific community, these values stimulate open debate and ensure rigorous analysis of data and hypotheses. Instead of offering restrictive problem–solutions that largely benefit self-serving perspectives, it is more appropriate to encourage nonegocentric thinking across various segments of society, so that intellectual standards and open-mindedness become core values of human affairs. As such, Epibraimatics would propose to take the risk entering king Minos' labyrinths of the unknown in search of true knowledge, identity, and purpose. In fact, one of the things that distinguishes Epibraimatics from many

[96] As revealed, e.g., by MRI scans.

mainstream thinking modes is its conviction that the search for meaning is intrinsic to real-world problem-solving. Scientific IPS, in particular, is meaningful to the extent that progressively and demonstratively moves toward important pragmatic goals (curing serious diseases, reducing poverty, improving education, eliminating hunger, etc.) and, equally important, it facilitates the inner needs of the scientist as an integrated human being (it contributes to one's struggle to understand oneself on many levels, and provides the means for an examined life that is worth living).

1.11.4 Challenges Faced by Epibraimatics

There are a number of questions to be considered in this book about Epibraimatics. How can it provide a viable IPS basis under in situ conditions? Can some guiding principles of sufficient methodological interest emerge from it? How can the adequacy and coherence of these principles be tested? What about the intermingling of science and philosophy in Epibraimatics? Which are the boundaries separating the formal from the interpretive, the practical from the philosophical, the physical from the metaphysical? For Epibraimatics to become part of the general lore in the current problem-solving culture, and not a fading fad, how should it establish a generally accepted framework that makes its ideas seem natural and useful? In sum, as is the case with any unfinished project, one must be prepared to face a variety of possibilities.

With these questions in mind, the IPS framework may be schematically summarized with the help of the following representation:

$$\left.\begin{array}{r}Localized\ \ brain\\ activities\end{array}\right\}\rightarrow\left.\begin{array}{r}Mental\\ functions\end{array}\right\}\rightarrow\left.\begin{array}{r}Fundamental\\ postulates\end{array}\right\}\rightarrow \\ \rightarrow\left.\begin{array}{r}Mathematical\\ operators\end{array}\right\}\rightarrow Problem\!-\!Solution \tag{1.7}$$

Mental functions emerge from brain activities in a way that reflects an adequate understanding of the dynamics of human nature (Chapter 3). These mental functions lead to certain methodological postulates that represent the essential features of the functions as close as possible. Finally, the postulates are translated into a set of mathematical operators that are used in IPS. Representation (1.7) forms the nucleus around which much of the book is developed. It hints at a *symbiosis* of elements from brain science, psychology, philosophy, and mathematics within the contemplated problem–solution context. Such a symbiosis promotes a twofold viewpoint: concrete and abstract. The *concrete* viewpoint directly senses, e.g., that an object is big or that an object is on the top of another, whereas the *abstract* viewpoint views the same objects in the wider context of size and spatial relations. The multileveled interaction and understanding emerging from the symbiosis could effectively avoid confusing the name of an entity with the entity itself, and judge what entity terms are the most useful (or the least misleading). To call a spade a spade, in a time of Decadence a thinker needs to be both within things and outside them; to develop the capacity to stand back from everyday experience and gain a broader IPS view.

Most of the work about consciousness is nowadays being carried out in neurosciences using technical languages and research methods within a narrow domain of inquiry – the investigation is of limited scope and the results are intimately linked to the experimental setup and data. But beyond the features investigated by neurosciences, consciousness has several other aspects (dynamic, inclusive, and integrative) that need to be taken into account too, which is why a symbiosis with other fields of inquiry (including philosophy, psychology, and linguistics) may be needed. In such a setting, the strong creative element of uncertainty should not escape one's attention. At any phase of its development, Epibraimatics is expected to possess sufficient structure (theories and mathematical formalisms), with previous successes built into this structure, and guiding methodological principles that can encompass the different disciplines and generate new advances. The structure must include criteria that determine what kinds of problem–solution reasoning are considered proper, what types of explanations are acceptable, what knowledge bases are consistent, and what counts as evidence in support or against a solution. The structure must also contain operational rules that govern the intra- and interdiscipline relations (causal and otherwise), as well as principles for distinguishing between them; and be sufficiently undogmatic to incorporate theoretical and experimental results that run counter to the inherited viewpoints of the various disciplines considered.

Understandably, at this point the main purpose of the concise representation (1.7) is to offer the readers an initial idea of the subject matter, whereas the various components of (1.7), their interrelationships and quantitative formulations, as well as possible means to test its adequacy will be discussed in Chapters 3–7. In these chapters, mathematical formulas will be introduced and, also, a new interpretational viewpoint will be assigned to old formulas linked to the quantitative IPS framework. But first, in Chapter 2, we will have a critical look at certain aspects of the IPS affair.

Chapter 2
Problem-Solving Revisited

"There is no problem that cannot be solved with a glass of brandy."

E. Hemingway

2.1 The Role of Philosophy in IPS

Philosophers have the reputation of intellectuals for whom an ability to uncork a wine is the apotheosis of practicality. Nevertheless, I am among those who believe that philosophy has numerous practical benefits. *Inter alia*, philosophy is an ideal subject for learning thinking skills. In this chapter, we will see how IPS can benefit considerably by integrating the argumentative and conceptual focus of philosophy with the rigor and effectiveness of the scientific approach. By integration, of course, is not meant the unification of the different sciences. IPS requires neither the development of common laws for all disciplines nor a common ontology. Yet it implies a set of shared skills and thinking style that make it possible to synthesize diverse knowledge sources from different disciplines and direct them toward the solution of the in situ problem.

2.1.1 Factual and Conceptual Features

It has been said that life is problem-solving. It has even been said that, "The primary question about life after death is not whether it is a fact, but even if it is, what problems that really solves."[1] Leaving afterlife problem-solving for another time and space, let us focus on present life concerns. Problem-solving is a human activity traditionally characterized as a form of thinking, a complex intellectual function, or a higher-order cognitive process that may require the modulation and control of basic or advanced skills (Goldstein and Levin 1987). The various IPS aspects have been studied in

[1] This statement is attributed to Ludwig Wittgenstein.

G. Christakos, *Integrative Problem-Solving in a Time of Decadence*,
DOI 10.1007/978-90-481-9890-0_2,

different fields, such as mathematics, logic, computer science, cognitive analysis, philosophy, sociology, and psychology. There was a time when the search for simplification and mathematical certainty was the dominant feature of a problem-solving approach, thus seriously limiting the domain of sciences (Morowitz 2002). In the real-world, a problem may represent a complex multidisciplinary situation, in which case its solution does not have a clear-cut and obvious meaning. This raises the profound question: What should be the main characteristics of a substantive solution to an in situ problem? Most investigators would agree that the answer to this question depends on one's worldview, conception of reality, ultimate presuppositions (conceptual and methodological), and tools (analytical, computational, and experimental). In this respect, the answer is linked to deeper issues of self-actualization, identity, and purpose that were discussed in Chapter 1.

The philosopher Rom Harré (2002) brings to our attention the crucial distinction between *factual* presumptions (i.e., concerning matters of fact and empirical evidence) and *conceptual* presumptions (concerning the meaning of concepts and the relations between them). With his careful analysis, Harré puts his finger on an important point. Every evidential base (observation, measurement, etc.) underlies a set of conceptual presumptions. The former relies on the latter, in the sense that the conceptual presumptions used to describe the evidence should be free of inconsistencies and contradictions (Section 1.7). This is valid for the same entity as well as for different entities that are related to each other within the boundaries of a specified system. Not only must the evidence obtained about a physical attribute fit the conceptual presumptions underlying this attribute but also the same evidence must not be in conflict with the conceptual presumptions underlying other physically and epistemically related attributes of the system. This important point is not fully appreciated in studies that transcend many fields, such as environmental exposure and health-risk assessment (Section 9.4). In the following, I will describe the science-philosophy affair and its practical value in the IPS setting.

2.1.2 Synthesis of Philosophical and Scientific Perspectives

Scientific IPS benefits significantly from the consideration of philosophical perspectives concerning the matter under investigation. History of science shows that mature disciplines are characterized by the close tie between science and philosophy (Frank 2004). This is true for physics and the fast advancing field of neuroscience as well. Werner Heisenberg discussed philosophy's vital role in the development of quantum physics in his celebrated volume *Physics and Philosophy* (Heisenberg 1958). Despite quantum theory's tremendous success, physicists are unsure about how it should be interpreted; they also realize that they cannot go forward unless they adopt an interpretation that is based on a sound philosophical position. In a similar vein, the neuroscientist Maxwell Bennett (2007: 163) expressed his strong conviction that: "I believe that every first-rate cognitive neuroscience laboratory now needs a very good critical, analytical philosopher."

Very important is philosophy's contribution to the solution of major existential problems linked to the potentially harmful consequences of scientific and technological developments. Modern science and technology have made it possible for certain individuals or small groups to cause – intentionally or unintentionally – the greatest imaginable damage to human civilization at a global scale. The intentional case refers to individuals or groups with a sociopolitical agenda to inflict large-scale destruction (e.g., biological attacks by a group of terrorists against a big city), whereas the unintentional case refers to major accidents (e.g., a nuclear explosion due to human error or miscalculation). The synthesis of philosophical and scientific perspectives can reconsider key concepts and presumptions, develop an adequate problem framework, and generate sustainable solutions that account for the multithematic features (technological, ethical, financial, etc.) of the problem. Given the ethical issues associated with the use of science, the collaboration between philosophy and science could be our only hope to resolve a potential crisis that can threaten the survival of our civilization.

Since science involves human practices that are based on certain presumptions, the role of philosophy is to bring these presumptions to critical scrutiny. As Wittgenstein used to say, "Philosophy unites the knots in our thinking that we have, in a senseless way, put there." This is an issue that amply demonstrates the high *practical* value of philosophy in IPS. An increasing number of people recognize that the failures of many scientific and engineering projects are, in large part, due to the inadequate presumptions taken for granted by the project investigators and the lack of any critical scrutiny of their conceptual and methodological underpinnings. As is well known, philosophy can be also useful in the context of the *demarcation* problem, i.e. the question of how to distinguish between science and pseudoscience. Moreover, owing to its nature, philosophical inquiry can help scientific IPS lay bare some questions about the phenomenon of interest that may have been hidden by the solutions. As far as Epibraimatics is concerned, the gist of the whole science–philosophy business may be summarized as follows: Philosophy is able to contribute to what on its face might otherwise appear to be an entire scientific issue, by helping to test and reshape intuition, frame the right questions, and gain a better understanding of key concepts that are driving the solution of the problem of interest. On the other hand, when necessary the philosophy's despair about certain deep issues of human inquiry (such as the possibility of knowledge) is balanced by science's spirit of intellectual optimism.

2.2 Historical Perspectives: From Heraclitus to Kuhn

Given the multidisciplinary character of most contemporary real-world problems, rational agents are obliged to seek novel ways of conceiving, formulating, and subsequently solving the problems in an integrative manner. Under the circumstances, philosophical investigation (a form of conceptual analysis) and scientific inquiry (including quantitative and action-based analysis) are complementary and made for each other. If philosophical experience is of any help, here we review some relevant perspectives developed over time. These are what the views of some major philosophers on IPS *might* have been according to their teachings. All possibilities are present, since these perspectives may be in complete agreement, properly complementary, or even contradict each other.

2.2.1 Heraclitus' River

Heraclitus (540–480 BC) believed that the only thing one can be sure of is that things are not going to stay the same and that everything is continually in flux. The universe changes according to a plan, with which the truly aware agent should cooperate. He used to say that, "One can never step into the same river twice." He also had offered an insight about randomness when he asserted that the *κόσμος* (kosmos, universe) that appears ordered and harmonious, is in fact a random product. Heraclitus' relevant quote was: "The fairest description of universe is but a randomly scattered dust-heap."

In a nutshell, what this all implies for IPS is that the perception of what constitutes an adequate solution changes with time and the varying multithematic context within which the solution is conceived. Otherwise said, a solution is not a fixed objective entity but rather a mental construct that exists in peoples' minds, and as such, it is influenced by a number of changing factors (environment, experience, and worldview). Hence, according to Heraclitus, a starting point of IPS should be the realization that the solution of an in situ problem is no more stable and fixed than the unstable environment in which it exists and evolves.

2.2.2 Parmenides Apology

Parmenides (c. 515-after 450 BC) made a conscious attempt to reconcile the world of appearance (of mortals, of *δόξα*) with the world of truth (of Gods), by explaining aspects of the former as a delusion due to erring mortals (Heidegger 1998). This monumental attempt, which is known as the *Parmenidean apology* (Popper 1998), admits that there is more than meets the eye in the world of appearance. Parmenidean apology exerted major influences on various aspects of human inquiry. One influential case of Parmenidean apology is the subjectivist interpretation of *probability theory*, which makes probability a consequence of human ignorance. The Parmenidean apology of *spatiotemporal analysis* is that because human agents are part of the world system we study and cannot place ourselves outside our four-dimensional environment (three spatial dimensions plus time), we cannot obtain an objective view of space–time. The Parmenidean apology of *thermodynamics* is that we are not fully informed – we are not Maxwell demons, but erring mortals. And last but not least, the Parmenidean apology of *modern physics* is that the observer or "the subject" necessarily invades the world of objective physics and subjectivizes it (in terms of the observer's apparatus).

Also, Parmenides emphasized the *unity* principle, according to which, matters of knowledge need to be internally harmonious within a complete whole before they can be judged as reliable. This is what in modern IPS terms is called "consistency." Scientific reasoning is the capacity to reason and connect items of information, and draw from them new conclusions, therefore extending our knowledge and understanding. As long as knowledge is a fluid thing, a problem–solution can be a "truth-in-the-making" at best. In sciences, the two worlds of Parmenides became the way of reason (*rationalism*) and the way of the senses (*empiricism*). A problem–solution should adequately integrate these two ways of thinking. The relevance of the Parmenidean apology to real-world IPS is multifold: The solution often encounters situations in which the Parmenidean apology offers meaningful and fruitful interpretations, and it results from a thought process seeking maximum knowledge and viewing reason and senses in a unified context.

2.2.3 Socrates' Maieutic

Socrates (469–399 BC) focused his philosophical investigations on humankind and was the first one to propose using *reason* to decide *moral* questions. The two cornerstones of Socrates' approach were: the methodical and purposeful questioning of the various elements of the issue at hand (e.g., the values, motivations, and perceptions linked to the issue), and the way the understanding of "truth" affects one's behavior. Socrates' approach was to "interrogate" his subjects in a way that prompted them to derive their own conclusions about the matter – a dialectic approach that became known as "maieutic" (*Μαιευτική*; Paniagua 1989). In a sense, Socratic's approach is a negative process of hypothesis elimination in that better hypotheses are found by steadily identifying and eliminating those that lead to contradictions.

In light of Socrates' approach, the IPS process would be broken down into a series of questions, the answers to which gradually distill the ultimate solution. In other words, deriving a solution to a real-world problem requires a relentless questioning of everything related to the problem in order to obtain a deeper understanding of the relevant values, motivations, and perceptions, and then suggesting combinations of models (physical, biological, sociological, and mathematical), which, acting in synergy, can help answer these questions. This viewpoint has been reconsidered these days by some researchers (e.g., Glass and Hall 2008), although not necessarily in exactly the same spirit as proposed by Socrates. The objective is not simply to solve an individual problem in some established yet mechanistic sense, but hopefully to improve one's way of thinking and value system, and, on that basis, one's integrative approach to problem-solving.

2.2.4 Plato's Forms and Value Invariance

Plato (427–347 BC) was the first to propose a theory of knowledge. In the view of many scholars, Plato offered an ingenious compromise between Heraclitus' flux and Parmenides' being, associating the former with the empirical and the latter with the intellectual. He viewed reality as a two-part affair, a changing part experienced through our senses and an unchanging or invariant part accessed only through our mental reflections. *Invariance* is one of Plato's ideas that plays a major role in modern physics. According to Paul Dirac (1947: vii), "the important things in the world appear as the invariants." Einstein later regretted that he called his work "Relativity theory" instead of *Invariantentheorie* (Nozick 2001: 78). In his famous allegory of the "Cave and the Divided Line," which is probably the most influential passage in Western philosophy ever written, Plato considered the world of the ephemeral (the shadows on the wall; a superficial world which, in itself, cannot be trusted to show us "the truth"), and the eternal world of *Forms* (that cast the shadows). Almost 2,500 years later, Plato's perspective is adopted in modern physics. According to Jonah Lehrer (Lehrer 2008: 18): "It turned out that Plato's pure forms – those unseen things that gave rise to everything else – were made out of subatomic particles, a surreal collection of electrons, neutrinos, gluons, and quarks of all directions . . . We build an $8 billion underground microscope [Large Hadron Collider] . . . We gather specs of near nothingness and then smash them together to re-create the very origins of the universe. We look at those shadows on the wall and can infer the forms that cast them." On the other hand, Plato would probably disagree with Jean Baudrillard's claim that photography has led to "the death of reality." Instead, Plato would view photographs as belonging to the world of the ephemeral, in the sense that they are images of the true reality, which is the world of Forms.

Plato's insight is aware of the critical link between Heraclitus' flux and Parmenides' unity and suggests that a problem–solution should be always viewed not as the ultimate truth but rather as an attempt to infer the (unknowable) reality from the recorded knowledge sources using sound reasoning. A useful IPS approach must have elements of conceptual truth that are invariant to ephemeral changes in its empirical characteristics. That is, to understand a problem, one may need to know the transformations it is invariant under. Nozick (2001), e.g., considers applications of the invariance concept in the solution of problems in a variety of scientific disciplines.

2.2.5 *Aristotle's Philosophy of Depths*

Aristotle (384–322 BC) promoted a different view than Plato about what can be known. *Φιλτατος ο Πλάτων, φιλτάτη δε η αλήθεια*[2] he once said, in an effort to distinguish his views from those of his teacher. Aristotle's own teaching dramatized, for the first time, a major split between those (like Plato) who see "reality" as being beyond direct human experience and those (like Aristotle) who see the only

[2] Dear is Plato, but dearest the truth.

ground for philosophy the world as we can experience it with our senses. According to an intriguing interpretation of Raphael's famous 1511 painting *The School of Athens*, Plato is pointing upward, arguing for his upward-oriented philosophy of heights, whereas Aristotle stands besides him extending his hand over the ground, in an attempt to defend his down-to-earth philosophy of depths.

Aristotle's associated four different causes to a solution: *material* cause, i.e., what the solution represents physically (a quantity, a process, etc.); *efficient* cause, i.e., how the solution is obtained (by means of analogical, taxonomic, or mathematical reasoning); *formal* cause, i.e., the "essence" of the solution (captured in terms of shape, pattern, etc.); and *final* cause, i.e., a goal, purpose, or intention associated with the solution (e.g., maximizing one's intellectual satisfaction, wealth, or pleasure). The last cause is sometimes referred to as a *teleological* feature of the solution and plays a special role in Epibraimatics. In addition, Aristotle promoted the view that a solution to a real-world problem should have a function and offer a sustainable benefit over time. That is, a solution *is* what it *does* for its user. A new development here is that a good IPS approach should balance Plato's intangible values with Aristotle's functional benefit.

2.2.6 Descartes' Cogito, Ergo Sum

Consensu omnium, René Descartes (1596–1650) brought philosophy into its modern era where the primacy of knowledge is explicitly acknowledged. In this respect, famous is Descartes' motto: *Cogito, ergo sum* (I think, therefore I am). According to Descartes, mental states and empirical findings are distinct and separate (this became known as the "mind–body dualism"). From Descartes onward, physical sciences have relied on the *reductionist* approach of a posteriori causation (cause precedes the effect), whereas a priori causation in the Aristotelian sense was considered unacceptable (Descartes 1641; Plotkin 1993).[3]

According to Descartes, when one is engaged with the solution of a new problem that presents several unknowns, one needs to use established rules as a practical guide but, also, be prepared that the shattering new insights will compel one to develop a fresh approach. This means that an IPS approach must identify the connection with its user's thoughts and innate ideas, and thereafter be the product of a purely rational (reductionistic) process. During this process, nonmaterial mental states could influence a material problem–solution. How this can be done, without invoking supernatural explanations, remains controversial to this day.

[3] Although the teleological explanation has gained ground in modern biological thinking (Lennox, 2000).

2.2.7 Spinoza's Omni Determinatio Est Negatio

Baruch Spinoza was one of the most importantt rationalists of seventeenth century Europe. Spinoza supported the superiority of human reason to the senses, he distinctively opposed Descartes' mind–body dualism, and he came to the conclusion that reason and senses are not separate, being a single identity. Spinoza was a determinist who held that absolutely everything that happens occurs through the operation of necessity (Spinoza's famous motto was, *Omni determinatio est negatio*; that is, all determination is negation). Therefore, human agents should seek to understand the necessary and eternal order of the world, in order to understand both their place in the world and what they ought to do in this world. Spinoza's philosophical system is considered by many thinkers as the purest example of rationalism.

According to Spinoza's line of thinking, how human agents think rationally about problem-solving, and what its empirical manifestation actually is, should be viewed as an integrated whole rather than as two separate entities. "Man is part of Nature," Spinoza famously wrote, "and must follow its laws." That in theory a meaningful IPS approach must satisfy some general principles of reasoning and in practice be consistent with empirical facts should be considered as a *unified entity*. This unification is a central element of Spinoza's philosophy. Therefore, when a theoretical problem–solution is unsatisfactory, it is probably because it is improperly related to the totality of the agent's experience.

2.2.8 Locke's Tabula Rasa

John Locke (1632–1710) was probably the first of the British empiricists, and he is considered one of the most influential of Enlightenment thinkers. For Locke, there are two kinds of sense-qualities of a bodily thing: Primary qualities that are quantitative and spatiotemporal (e.g., size, texture, and motion), and secondary qualities that are qualitative and nonspatiotemporal (e.g., color, sound, and taste). Unlike Galileo and Descartes who considered the secondary properties to be subjective (in the mind of the observer), Locke held all qualities to be objective (part of the world). Also, contrary to the Cartesian philosophy, Locke believed that humans are born without innate ideas, i.e., they are born with minds like blank slates (*tabula rasa*). All knowledge is derived from experience through the action of the physical world upon an agent's senses. The theory of *tabula rasa* is not substantiated by scientific findings. Similarly, the idea that both the primary and the secondary qualities of a thing are objective is incorrect, since agents are unaware of the primary qualities except through the medium of the secondary qualities; if the secondary are unreliable (being largely subjective), there is no reason to believe in the actuality of the primary qualities.

To satisfy the Lockean viewpoint, a problem–solution should primarily fit empirical findings ("let the data speak for themselves"), often independent of thought processes. As the readers know, this is a highly controversial viewpoint (the matter arises in various parts of this book). Empiricism dismisses the Cartesian view that a solution should result from a rational process that accounts for the agent's thoughts and motivations. In a similar way, empiricism contradicts Spinoza's unification of thought process and empirical manifestation. The result is an agglomeration of conflicting theories. Nevertheless, much of mainstream statistics is basically Lockean, producing purely data-driven solutions that often do not escape the fatal confounding of sense knowledge with intellectual knowledge.

2.2.9 Hume's Skepticism

Without being as extreme as Locke, the Scottish philosopher David Hume (1711–1776) favored a *skeptical* approach to human inquiry according to which knowledge is restricted to what can be experienced. Unlike Locke, Hume argued that one could form beliefs about matters that are beyond one's experience by using one's imagination, but he was skeptical about claims to knowledge on this basis. A key element of Hume's approach is that he doubted human claims to knowledge by effectively involving psychological considerations into the process. His philosophical question whether inductive reasoning can lead to truth became known as *Hume's problem of induction*.

Hume's skepticism essentially implies that a problem–solution can only be a *probable* one. Accordingly, the solution is based on perceptual knowledge (that comes via direct or indirect experience), and as such, the knowledge is subjective and incomplete. The solution process is inductive, starting with a set of specific empirical findings and developing generalizations that are not certain. An inductive solution fits as closely as possible the data available and produces results (e.g., interpolated and extrapolated attribute values at unobservable points) that are uncertain to a larger or a smaller degree. However, the main justification of induction is that it is expected to work in the future because it has worked in the past, which makes the justification perilously circular. On the other hand, when properly combined with complementary types of reasoning, induction can be a valuable IPS tool under conditions of uncertainty (Section 5.2.1).

2.2.10 Kant's Synthesis

Immanuel Kant (1724–1804) explicitly distinguished between the *noumenal* world (world of things in themselves), which remains unknown to us, and the *phenomenal* world (world of appearances), about which we can know certain things.[4] This is the

[4] The readers may notice the close resemblance with the two worlds of Parmenides.

meaning of Kant's *Ding an sich*; after all, the real-world is infinite complex, whereas a mind is finite. Despite its finiteness, the role of mind is thus critical, since it shapes, categorizes, and organizes the experiences that constitute the phenomenal world (raw data that come from our senses). Kant famously said that, "Our intellect does not draw its laws from nature, but imposes its laws upon Nature." Kant considered as a good solution to a real-world problem that which is the synthesis of the rational and empirical thinking modes. For him, experience without theory is blind, and theory without experience is mere intellectual play. This synthesis was another major step forward that blended in a compelling way what can be thought (inside our brains) and what can be experienced (by means of our senses and tools). And in this way, Kant's work contributed decisively in the resolution of the historical split between Plato's and Aristotle's philosophies concerning what can be known.

Kant's synthesis accounts for the limits of knowledge: IPS is determined by what we are capable of knowing on the basis of the limited means available to us for gathering, assimilating, and using diverse data sources. Hence, a solution to a real-world problem is more about the way our minds work than it is about the way reality really is. Intuition and concepts constitute the elements of all human knowledge, so that neither concepts without an intuition in some way corresponding to them, nor intuition without concepts, can yield knowledge. The solution is determined by the subject (observer) and is not merely an inherent quality of the object (the observed).

2.2.11 Hegel's Dialectics

Georg Wilhelm Hegel (1770–1831) believed that any given phenomenon (thesis) contains within itself contradictory aspects (antithesis) that require a movement toward resolution (synthesis). Progress in understanding reality occurs according to a process that has this *dialectical* form. Hence, knowledge is a dynamic culture and not a pre-existing and timeless thing waiting to be discovered.

Hegel's philosophical reference frame implies that an IPS is the outcome of a dialectical process of change that has both an underlying structure and an ultimate goal. In German, this state is called *Geist* (a term that includes a sense of "consciousness" and "spirit"). The thus obtained problem–solution is context-dependent and emanates from the agent's consciousness, which itself is continually changing and developing new concepts and perspectives about important aspects of the real-world. For some Hegelians, the ultimate goal of the dialectical process is a state of understanding and self-fulfillment (which is similar to the Parmenidean *νοεὶν*). In modern IPS, the dialectical goal could be the maximization of a suitable quantity (utility) associated with the problem at hand. It should be mentioned in passing that Hegel's dialectical approach to IPS is similar to Socrates' questioning approach, in the sense that they both involve the possibility of conflict and tension between the opposing views and theses considered.

2.2.12 Darwin's Evolutionary Adaptation

For Charles Darwin (1809–1882), *adaptation* is a basic macrofeature of an organism (anatomical structure, physiological pattern, or behavioral trait) formed by a long *evolutionary* process of natural selection and interaction with the organism's environment in a manner that improves its expected chances of survival and reproduction. Otherwise said, Darwin approached philosophical problems through natural history.

The adaptation concept plays a central role in Darwin's evolutionary philosophy, and also has important consequences in IPS, since the brain's ability to acquire, appraise, and synthesize knowledge possesses an adaptational sense. For *evolutionary epistemology* (Section 3.2.1), knowledge development is the outcome of variation and selection processes involving potential knowledge sources. In evolutionary epistemology, a typical pattern of scientific inquiry includes multiple hypotheses generation by various means (variation) and subsequent elimination of those hypotheses that are considered inadequate (selection). In a similar manner, a problem–solution should be adequately adapted to the problem's specific contextual environment, and those potential solutions that fail to do so should be eliminated. For example, an initial solution obtained from core knowledge should be adapted in the light of the case-specific data that become available at a certain stage of the solution process.

2.2.13 Wittgenstein's Living Practice

For Ludwig Wittgenstein (1889–1951), philosophy can only address the part of the world that we can perceive by virtue of our senses. His intellectual construct focused on the connections between perception, thought, language, and expression – with the most important element being the centrality of *language*. He demonstrated the many ways in which human language functions in the real-world and distinguished it from the purified (purely logical) language in which the various shades of meaning and subtleties have been eliminated. For Wittgenstein, there is a vital connection between one's *use* of language (what one does with it, when and where one writes/says what one writes/says)[5] and the *meaning* of the words and symbols one uses. In a sense, language works because it presents a picture of reality. A picture represents something that is or could have been the case had the world turned out differently. Meaning is more than about picturing reality; it is about the different ways language is used and the various ways in which it works.

Since a problem and its solution are expressed in linguistic terms (words, symbols, signs, and concepts are employed to describe phenomena and relations), questions may arise concerning the meaning of these terms and their role in connecting mental and natural states involved in IPS. To discuss the deepest issues

[5] Which, in a sense, is related to Aristotle's notion of functionality.

of a real-world problem, we need to use a language with all its richness and ability to embrace metaphors and multiplicity and even tolerate paradox. In this sense, the language we use is not a determinate system specified in precise logical terms only, but a *living practice* that can be employed in a number of contexts for a variety of different purposes. Since the solution often depends on the way the problem is described, in many cases the real issue is not that one does not know the solution, but rather that one does not understand the problem. Hence, the problem–solution has not a single meaning, but rather several meanings derived from the different ways in which the solution is expressed linguistically, understood, and used in real-world situations. One should not limit progress by assuming that the solution of a problem necessarily means one thing; rather a solution's meaning is the combination of all its uses and values.

2.2.14 Popper's Constructive Criticism

Sir Karl Raimund Popper (1902–1994) has maintained that one simply cannot observe a natural process without first having some theoretical notion of its significance. Popper's open society functions on the basis of educated skepticism, whereas his famous *falsification* concept (Section 1.1.2) is based on the view that no theory can be proven right, although every theory can be potentially proven wrong (Popper 1934). He viewed falsification as an adequate solution of Hume's problem of induction, although not everybody agrees with him on this.

According to Popper's mode of thinking, a scientific problem–solution should be derived in terms of a pluralistic approach that eliminates alternatives by fostering a culture of *constructive criticism*. This is because for Popper falsification constitutes an effective way to distinguish between a scientific and a nonscientific solution (i.e., it can be used as a definite demarcation criterion for IPS purposes). The problem–solution exists independent of the human agent and can be tested through experimentation. It does not represent certain knowledge, and is primarily based on an intellectual model that has "worked" so far but should be replaced when a new, more productive theory is developed. Accordingly, Popper was against induction and rather favored the use of a hypothetico-deductive mode of reasoning in IPS (Section 5.2.1.4). Many of Popper's views have influenced a considerable number of scientific problem-solvers during the twentieth century and continue to do so up to nowadays.

2.2.15 Kuhn's Paradigm

While Karl Popper adopted a normative view of epistemology (how scientists should operate), Thomas Kuhn (1922–1996) favored a sociological view of epistemology (how scientists, in fact, operate as a social system). Kuhn introduced a historical perspective in the study of scientific practice and used the term *paradigm* (Section 1.7.3.2) to describe a particular way of looking at things. The paradigm includes a set of theories, laws, techniques, applications, and instrumentation together. Accordingly, a paradigm is more than a theory but less than a worldview (Kuhn 1962). Remarkably, over the years Kuhn's perspective has been considered in the context of several different disciplines and, at the same time, it has also been misunderstood in many different ways. Kuhn's ideas have been very influential, although more recent scholars argue that he did not pay sufficient attention to the sociological forces that bound a group to its paradigm.

From Kuhn's reference frame, IPS should be generally viewed as a process strictly determined by what Kuhn called *normal science*, i.e., the dominant framework of actual scientific practice that decides the problems worth studying, the theoretical methods to be used, and experiments to be performed in attempting to solve these problems; it establishes the peer-review procedures that control both the boundaries of accepted solutions and their quality. Even data and experiments are subject to different interpretations.[6] Eventually, it is the accumulated inability of a paradigm to solve new problems and explain the emerging phenomena that make it necessary to replace the paradigm with a new one. However, replacing the old paradigm is usually not as straightforward an affair as it may seem, even if the accumulated evidence against the paradigm is overwhelming. Senior scientists who have built their professional reputation around the old paradigm will go out of their way to defend it, even if strong evidence against it exists, which may explain, e.g., why scientists who defend their use of regression models in environmental exposure studies refuse to participate in an open discussion that could question the usefulness of these models (Section 9.4). As a matter of fact, Kuhn believed that in most cases a new paradigm is accepted, not because of the persuasive force of striking new evidence, but because old scientists die out and young ones, who have no vested interests in the old paradigm and are troubled by its inadequacy, decide to replace it with the new one. That is, paradigm change is a synthesis of scientific and social forces working in parallel.

An interesting Kuhnian phenomenon emerges when in order to win acceptance of their ideas and methods, newcomers in a field decide to change the "evidential context" of their work, i.e., to search for a new evidential context into which their work can fit nicely and be accepted, while avoiding the old context dominated by the orthodox view of the core-group in that context. For example, common is the case of uncertainty modelers who, instead of wasting their time trying to convince in vain the statistics orthodoxy about the value of their work, chose to present their ideas to new audiences of scientists and engineers. The statistics orthodoxy soon becomes aware that these ideas have come to the ears of new audiences, which clearly presents a threat to its authority, and reacts accordingly. This is how the so-called "turf wars" usually start.

[6] As happened with many original thinkers before him, the clerkdom deeply disliked Kuhn's views, because they questioned the merit of the established framework that worked to the advantage of the ruling elites.

2.3 Rethink Everything

Philosophy is often practiced as a form of conceptual analysis, in which case the aim of the previous section was to consider IPS from a variety of philosophical perspectives. Some of the perspectives were built on preceding ones, whereas others sought to overturn established theories. It is worth the effort to develop a conception of what a *solution* to a real-world problem is by incorporating elements of the above philosophical perspectives together with a scientific assessment of the in situ situation.

2.3.1 Che Fece . . . Il Gran Rifiuto

Since science can have a significant social component, one should not neglect the fact that searching for something out of the ordinary, like a novel IPS approach, has broader consequences, and one should be prepared to deal with them accordingly.

2.3.1.1 In Berlin You Will not Fit in

As noted earlier, there is nothing that the scientific cabals dislike more than new ideas that could question established practices. Fighting quality, especially when it originates outside their own club, has always been a top priority for the cabals. This has the result that many highly promising young investigators forever remain in the shadows. The situation reminds one of Nicollò Paganini's advice to a brilliant young violinist: "You are very good, but make sure that nobody listens you play the violin."[7] According to Vilayanur S. Ramachandran (2006: 49), "People who are in the same club engage in mutual admiration and reward each other by funding each other. Their papers are 'peer reviewed' by people in their own clubs, and as a result, no one seriously questions the meaning of the whole enterprise or where it is headed. Anyone who dares to do so is in danger of excommunication by the priesthood, so to speak." It is common knowledge that the "conform-or-perish" rule of the clerkdom strictly demands that its members routinely demonstrate their loyalty by resorting to means closely resembling the medieval obeyance most infamously expressed by the act of kissing the *Cardinal's ring*.

As an authoritarian social unit, the established clerkdom has its own rigid behavioral codes that, however shallow they may be, should be religiously observed

[7] Paganini was a celebrated nineteenth century Italian violinist and composer, considered by many as the greatest violin virtuoso of all time.

and never be violated (Section 1.4.2). The following is a telling incident linked to Ludwig Boltzmann's visit to Berlin, where he was considering a possible faculty appointment. One evening, during dinner Boltzmann picked up the wrong piece of cutlery, at which moment the wife of a Berlin professor turned to him and uttered the fateful phrase: "Herr Boltzmann, in Berlin you will not fit in." David Lindley (2001: 102) infers that, "Some inner hesitation prevented Boltzmann from following through on his acceptance of the Berlin offer." Boltzmann was a pioneer in many fields of scientific inquiry, but his many contributions were recognized after his death, which shows that death can be a good career move for those who are not favored by the power holders of their time.[8]

2.3.1.2 The Big Yes and the Big No

Eventually, a time comes in a Man's life when one has to choose between the big "Yes" or the big "No" to the dilemma imposed by the clerkdom, which is the message of Constantin P. Cavafy's poem *Che fece ... il gran rifiuto* (Cavafy 2007):[9]

> There comes a day for certain types when they
> must say the noble Yes – or noble No.
> The one who has the Yes within will show
> himself prepared by speaking it, to say
> that he proceeds on faith and sense of pride.
> The one who doesn't have it doesn't fret;
> if asked again, he'll still say No, and yet
> that proper No must evermore abide.

For those who, despite the odds, chose the big *No*, an adequate analysis of the IPS situation will depend on the honest assessment and careful elaboration of its paradigmatic context, essential concepts, underlying assumptions, and knowledge sources, and not on criteria that merely serve the agenda of the clerkdom that currently dominates the field. On occasion, this big *Yes* is the rock on which attempts to build new theories and better solutions are foundering.

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[8] David Hilbert recognized the importance of the Boltzmann equation and proposed a method for obtaining approximate solutions. Ergodic theory is based on Boltzmann's statistical mechanics concepts. He anticipated Thomas Kuhn's views on scientific revolutions. He applied Charles Darwin's theory to the evolution of the mind, anticipating certain aspects of evolutionary epistemology and the theory of science later proposed by Konrad Lorenz and Karl Popper. "In his realization of the hypothetical character of all our knowledge, Boltzmann was far ahead of his time and perhaps even our time", said Paul Feyerabend.

[9] Cavafy borrowed his poem's title from Dante's *Inferno* (iii, 60); the title means "Who made...the great refusal." Cavafy deliberately omitted the words *per vilta* ("because of cowardice").

2.3.1.3 The Need for a Fresh Look

Before proceeding any further, let us consider a plausible question: Why is a fresh look at problem-solving constantly needed in science? There are at least four interrelated answers to this question. First, ongoing developments in interdisciplinary sciences require that one reconsiders the manner a problem is *conceived* and *presented*. If a problem is conceived in a misleading manner, its solution will probably turn out to be meaningless and utterly useless. In Douglas Adams‘s book *The Hitch-Hikers Guide to the Galaxy*, the quality of the answers provided by the most powerful computer ever built (the so-called “Deep Thought”) depends heavily on the structure of the questions asked. Adequate problem conception and representation should be a synthesis of different viewpoints. If the right questions are asked, one should expect to get the right answer. Otherwise, the situation resembles what in computer science is called GIGO: “Garbage in, garbage out.” Second, the target is not so much the solution of closed-system problems (ideal for a preliminary mathematical analysis, yet usually representing unrealistic situations), but rather the solution of in situ *open-system* problems (Section 1.8.2.1). Gregory Chaitin’s suggestion is that (Chaitin 2005; 12–13), “You have to shut your eyes and focus on only one tiny little aspect of the problem . . . But after the brief elation of ‘victory,’ you, or other people who come after you, begin to realize that the problem that you solved was only a toy version of the real problem, one that leaves out significant aspects of the problem . . . And those forgotten aspects of the problem never go away entirely: Instead they just wait patiently outside your cozy little mental construct, biding their time, knowing that at some point someone else is going to have to take them seriously.” Third, many in situ problems are messy, perplexing and even contain contradictory elements. Their solution requires that one’s thinking mode extends beyond ordinary thinking into the domain of *creative* thinking. This is a serious step, since most mainstream problem–solution techniques are built on the basis of the former rather than the latter thinking mode. And fourth, findings in brain and neuropsychological sciences have significantly affected the way many fields look at themselves and at the problem–solution process (Read 2008). The possibility should be examined that mainstream problem-solving based on the design of a set of general content-independent formal rules is outdated and a fresh look at a *content-dependent* solution approach is necessary. One may plausibly anticipate that an IPS theory designed to fit neuropsychological and behavioral brain features shaped during many years of evolution would be more efficiently implemented by the human brain than the mechanistically designed mainstream approaches.

The take-home message is that in today’s world many problems are becoming too large and complex to be confronted by conventional means. In this respect, while physical science has progressed by leaving out the consideration of mental states, this is no longer the case: There is more to real-world problem-solving than is understood by physical science methods alone.

2.3.2 Problem Formulation and Solution Meaning: Einstein's 19/20 Rule

I will now focus on the very important yet not sufficiently appreciated fact that in the real-world the greatest obstacles often arise from the way the problem is formulated and the meaning one assigns to its anticipated solution, rather than by finding the right IPS method to solve the problem. To quote Einstein,

> If I had 20 days to solve a problem, I would take 19 days to define it.

Likewise, before painting the final form of his masterpiece *Les Demoiselles d'Avignon*, Pablo Picasso spent countless days with preliminary sketches, since for him, "To model an object is to possess it." Ignoring any advice, many contemporary, investigators do not spend sufficient time to explore and understand all the key elements of a new problem, before making an attempt to derive a solution. It is like a new body is brought on the table and dissected before it has had time to cool.

The formulation of many in situ problems requires an integrative discussion of the issues raised by the contributing disciplines about themselves as well as about their relations with others. Decisions made in an integrative manner may address issues like, whether the problem and its solution should be studied from an "inside" subjective perspective or an "outside" objective perspective, and what is the significance of this decision. As a result of this integrative effort the participating investigators may gain new knowledge and ideas to use profitably in their own disciplines or they may find it appropriate to pay more attention to the openness of notions and purposes upon which their disciplines were built.

2.3.2.1 Travelers' Tales in Cancer Research

Health sciences provide several high-profile cases in which the scientific effort focuses on the solution of an artificial problem that has little in common with the actual problem. Such is the case of cancer research. In a widely cited article, Clifton Leaf discussed the failure of the war against cancer. For Leaf (2004), cancer research is fundamentally flawed in its orientation. He quoted one of U.S.A.'s most celebrated cancer researchers, Dr. Robert Weinberg of the Massachusetts Institute of Technology: "A fundamental problem which remains to be solved in the whole cancer research effort, in terms of therapies, is that the pre-clinical models of human cancer, in large part, stink." Why then are these inadequate problem perceptions and misleading models still being used?

The answer turns out to be rather simple: these artificial models are "very convenient, easily manipulated," says Vishva Dixit of the Genentech company. Cancer scientists have self-confidently created "animal models" that supposedly mimic an equivalent human disease. These scientists then triumphantly "cure" cancer in these laboratory models. But cell lines and tumors growing in mice are drastically different from spontaneous human tumors. A flawed model is not likely to yield useful results. Those who closely follow the cancer field have become inured to an endless series of "breakthroughs" in mice that almost never pan out when tried in the clinic. It seems that ordinary humans are a species with which many cancer researchers are unlikely to have had first-hand acquaintance, although, to be fair, they may have heard travelers' tales about them. "Hundreds of millions of dollars are being wasted every year by drug companies using these models," says Weinberg. As a result, despite the huge amount of money spent on cancer research (the total amount of funding, from a variety of sources, has been about $200 billion for the period 1971–2004), the research has become increasingly irrelevant to the real-life problems faced by cancer patients.

2.3.2.2 The Sequence

A problem formulation develops in the agent's mind as a thought, whereas its physical manifestation is a product of the mental state and the in situ conditions. An adequate formulation must account for the multifaceted characteristics of reality. The sequence involving the three entities, "real-world system Q," "problem Π linked to Q," and "representation M of Q," is not always a clear-cut affair. One may consider several possibilities, two of which are discussed below. These and similar possibilities suggest a distinction between problem-formulation and problem-solving, where each has its own informational needs.

Case 1: A problem Π is carefully defined, and the "right" system Q is chosen that offers a sound framework for solving Π. A model M is developed that represents Q adequately (in some sense), is consistent with the needs of Π, and can be studied with the existing (experimental, analytical or computational) tools. Consider, e.g., the problem Π: *Does the birth control pill cause birth defects to women*? The associated system could be, say, Q: *European white women between 20 and 35 years old*. Then, a model M may use study participants at the county scale and monthly intervals and involve first-order pharmacokinetics (Christakos and Hristopulos 1998).

Case 2: A real-world system Q exists, and a problem Π linked to Q is subsequently described. Consider, e.g., the real-world system, Q: *San Diego county and the exposure conditions to certain pollutant X*. The corresponding problem may be Π: *Does exposure to X cause cancer to residents of the San Diego county?* A model M may be chosen that combines samples from specific geographical regions and time periods, a pollutant space-time distribution law, and a stochastic toxicology theory.

Notice that in Case 1 the sequence was "Π-Q-M," whereas in Case 2 it was "Q-Π-M." The steps involved in each sequence are by no means trivial. A number of issues arise. Is in Case 1 the selected system Q satisfactory for the problem Π? Should Q include women of all ages, races, and nationalities or should focus on a specific group? Is the model M an adequate choice or a multicompartmental model of higher-order pharmacokinetics should be used? Similar questions may be valid for Case 2. Surely, the investigator's prime goal should be to develop an adequate problem-formulation that does not obscure the real issues by piling up irrelevancies around them. Moreover, the matter with some solutions is not that they have a specific aspect (say empirical), but that they have nothing else. Empirical biostatistics based on unexplained correlations, e.g., while useful in capturing elements common in groups of similar systems, does not necessarily capture essential features of the actual open system as expressed by the underlying laws of space–time change, outside influences and dependencies, boundary conditions, and secondary effects. In a large number of cases, a well-established convention is to formally express the representation or model M as follows

$$M(a_i,\ BIC,\ X) = 0 \tag{2.1}$$

where $a_i\ (i = 1, 2, ...)$ are input coefficients, BIC denotes boundary and initial conditions, and X is the attribute of concern that is distributed across space–time. Admittedly, a problem formulation of the form (2.1) is more rigorously established in exact sciences (in which a high level of theorizing combined with adequate experimentation is the norm) rather than in nonexact sciences (where the attention focuses on experiments, and theorizing is rather underdeveloped).

2.3.2.3 Questions of Meaning

Understanding a problem is an authentic act that assigns *meaning* to objects. In a sense, the meaning expresses the mind's reaction to its inherent decay, just as time imprints body's resistance to its progressive decay. The conventional problem formulation raises a fundamental question. In light of well-known knowledge reliability issues linked to the measurement (or observation) of a_i and BIC, approximations in the technical form and physical interpretation of X, conceptual uncertainty concerning the model M, and the open-system Q effects, what is the meaning of a solution based on formulation (2.1)? As a matter of fact, a motivation for the development of an improved solution meaning is the realization that the conventional solution concept may suffer from a twofold inadequacy, as follows:

The *abstraction* inadequacy: Reality is viewed as a set of abstract mathematics of the form (2.1). This abstraction, regardless of its usefulness, remains a creation of the human mind rather than reality itself, which means that Eq. (2.1) could be an incomplete in situ representation. Many thinkers raise plausible questions concerning the general validity of current mathematics in real-world circumstances. One of them is Gregory Chaitin (2005: 16): "How much of our current mathematics is habit, and how much is essential? . . . Would mathematics done on another planet by intelligent aliens be similar to or very different from ours?" It is not sufficient that an abstraction is rigorous according to the current mathematical fashion. The real issues are whether this abstraction is relevant, whether it adequately represents the actual problem, and whether it offers insight and points to important directions. These issues are related to language matters, as discussed by Ludwig Wittgenstein and Niels Bohr (Section 3.7). Mathematical abstractions, including those representing physical laws, are not universal truths corresponding exactly to the real system but rather an approximation valid within restricted domains. Mainstream techniques sometimes try in vain to derive a picture of what a solution should formally look like to fit in with preconceived ideas derived from closed-form considerations of the physical system or past experiments. Under the circumstances, it is possible that a formal solution of the model M has limited similarity with the actual behavior of the in situ problem Π. Typical is the case of so-called "aggressive ignorance": mathematical models combined with experimental techniques are employed to represent what definitely is a poorly understood phenomenon, in which case the models have little to do with the actual phenomenon they represent, and the experiments have no relevance with the attributes they are supposed to measure. An extreme case of senseless use of mathematics to describe the unknown reality is found in finance and economics. In these fields, many individuals have made a highly profitable career by subscribing to an approach that Nassim N. Taleb (2008a: xviii) calls "dressing up the intellectual fraud with mathematics."[10]

The *solution* inadequacy: One often conceives as problem "solution" the numerical realization χ of the attribute X that is determined according to the formal convention

$$X = \chi: \quad M(\alpha_i,\ \chi_{BIC},\ \chi) = 0 \tag{2.2}$$

where α_i $(i = 1, 2, ...)$ are specified values of the coefficients a_i in Eq. (2.1), and χ_{BIC} denotes the attribute values at the system boundaries and time origin. The crux of the matter is that formulation (2.2) is not necessarily physically meaningful and, as is explained in more detail later, the reason for this is multifold. The first reason is the inadequacy of the abstraction itself. Formal mathematics view (2.1) as a collection of symbols linked in a logical manner, which implies that the solution (2.2) is a matter of applying purely formal definitions and theorems. But, knowing how to solve an equation does not necessarily mean that one comprehends the deeper meaning of what one has solved. A second reason is that the solution (2.2) is restricted by the fact that it must be expressed in terms of the currently available mathematical formalism. This is not always an adequate approach in complex real-world studies given the inherent limitations of the formalism. To put the matter in slightly different terms, the way the problem is formulated also determines the kind of solution one anticipates. If the problem is formulated in terms of deterministic variables, the solution will be expressed in terms of numbers (values of the variables), whereas if the problem is described in terms of shapes (e.g., probability distributions), the solution will be expressed in terms of shapes too. A third reason is that in several cases the solution (2.2) may not even exist in a rigorous sense, which

[10] Yet, one cannot blame mathematics for its inappropriate use by some people, which seems to escape Taleb's attention. As a result, his otherwise thoughtful book contains some unfair criticisms of the mathematical method.

is kind of paradoxical, since the phenomenon that mathematics are called upon to study is a reality that can be observed and appreciated. Otherwise said, the notion of reality may be beyond the boundaries of known mathematics. In the words of Wolfgang Pauli, “That which we come upon, which is beyond our power of choice, and with which we have to reckon, is what we designate as real.” Approximate numerical schemes that are proposed to replace the mathematical solution may be logically inconsistent. The readers should not have any difficulty guessing the sources of these logical problems. For example, since the exact (analytical) solution is unknown to the investigator, one may question the meaning of the term “approximate.” Indeed, a legitimate question would be: Approximate solution with respect to what?

2.3.2.4 The “Cargo” Solution

Related to matters of solution inadequacy as described above is the so-called *cargo* problem–solution: what may appear to be a solution (it satisfies the problem’s statement in a certain sense) but, nevertheless, lacks the substance that would have made it a real solution. The characterization “cargo” belongs to Richard Feynman. To illustrate the situation in his own unique way, Feynman (1985: 308–317) referred to the case of the aboriginal islanders of the South Pacific. The problem that these islanders had after the Second World War was how to make the U.S. cargo planes return with all kinds of goods. The islanders’ solution to the problem was to erect towers and wooden antennas near the airstrip, act like controllers, and then wait for the planes to come in. This was, clearly, an “apparent” solution: it had a form that seemed to be correct but, nevertheless, it lacked any substance, and so, naturally, in the end no planes came in.

One finds an increasing number of “cargo” studies in the literature. Leo Breiman (1983) described a major U.S. health study that used complex multiple time-series techniques that were nonetheless totally irrelevant to the problem at hand (due to the lack of substantive content, incompatible measurement procedures, and misinterpreted data). Several decades later, this “cargo” mindset continues to characterize corporate geostatistics and its profound neglect of substantive issues. For example, every time Pierre Goovaerts faces a problem, no matter if it is about cancer incidence, exposure assessment, soil properties, crime date, or racial disparities, the answer is always the same: “Krige it” (Goovaerts 1997, 2008, 2009, 2010a, b). Then, if he actually possesses “Midas touch,” as he seems to believe, one would assume that the queues outside Goovaerts’ office are as long as those outside Lenin’s mausoleum during the Soviet era. Similarly, empirical models that routinely focus on unexplained correlations and the outward appearance of physical evidence but neglect its inward significance (e.g., De Gunst et al. 2001; Gelpke and Künsch 2001) should be always considered *cum grano salis*.[11] Such models often mistake random noise for information, lack physical substance, and rely on unrealistic technicalities, thus shifting the

[11] Commonly used expression meaning “with a grain of salt.”

emphasis of reasoning from scientific truths that are verifiable to "narratives" that can be manufactured. In short, rarely do any interesting results come out of "cargo" studies due to their innate sociocentrism that focuses on trivial formulations of the phenomenon, uses information in a self-serving way, and lacks epistemic essence and substantive interpretation.

2.3.3 Taking Stock: Four Key Elements

Metaphorically speaking, the conventional perspective of problem–solution may resemble a machine that operates on Eq. (2.1) according to a set of formal rules to produce solutions of the form of Eq. (2.2). It is increasingly recognized that this perspective does not pay sufficient attention to four critical elements (which, in a way, constitute a restatement of the four plausible answers previously considered in Section 2.3.1.3): (a) knowledge *reliability* issues concerning the applicability of formal constructions (like model M) to in situ situations; (b) *neuropsychological* findings concerning the way the mind functions and its relation to human inquiry (including problem-solving); (c) the lack of an *externalist* perspective, i.e., the paradox that the agent is at the same time observer and part of what is trying to observe and comprehend (Section 1.6); (d) understanding the nature of the problem by examining its *environment*, including the social and informational reality of system Q.

Concerning element (a), knowing the principles and techniques of a scientific field and applying them in a real-world problem can be two different things. For illustration purposes, imagine someone who has an excellent formal knowledge of physics (allowing one to solve all kinds of theoretical problems) and, yet, one cannot apply basic physical laws to address real-world concerns, like driving a car or riding a bicycle. Famous is the case of the great theoretical physicist Werner Heisenberg who almost failed his Doctorate examination because he could not explain how a storage battery works (Powers 1993). Concerning element (b), the fact that the human brain has been a critical factor in human survival for thousands of years should be a good enough reason to consider its main operations in the search for meaning concerning the term "problem–solution." This is a topic that will keep us busy in various parts of the book. About element (c), there cannot be such a thing as "a true, complete, and unique representation of the real system Q." That is, there can be no God's eye view of reality. Such a representation would presuppose, at a minimum, a privileged correct description from an externalist perspective of reality, whereas human agents have only a restricted "internalist" perspective from within reality. Lastly, concerning element (d) solutions that isolate the problem from its environment are often meaningless. Again, let us allow ourselves to use a metaphor: The solution of a problem may vary considerably, depending on its environment just as a plant varies in taste and form depending on the local climate, on the soil in which it is planted, on the fertilizer used, and even on the potential use of grafts that may produce a fruit quite different from its predecessors. Also, in the multidisciplinary (intra- and interdisciplinary) environment of element (d), the agent is an *interpreting* and an *interpreted* being at the same time. In such cases, the environment contains information that is not limited to one's sensory immediacy.

2.3.4 Different Kinds of Problem–Solutions

The discussion so far clearly shows that in the IPS front, the learning challenges are immense. A solution framework needs to pay sufficient attention to the problem content and context. Hence, a problem–solution should involve (*inter alia*) the use of epistemic tools for conceptual clarification and exploration, for examining the meaning and implications of concepts and argumentation modes, and for considering the realizability of the generated solutions.

2.3.4.1 Problem–Solution Realizability

Concerning the *realizability* of the generated problem–solution, basically one may distinguish between: (i) a solution that is *physically* possible, because it does not violate any physical law; (ii) a solution that is *practically* possible, because it is physically meaningful and we currently possess the technical and other means to materialize it; and (iii) a solution that is *logically* possible, since it does not violate the laws of logic. Clearly, a solution can be physically possible but not practically so (it may be beyond the currently available means). Also, a solution can be logically but not physically or practically possible. In some cases, a problem–solution should not go beyond what is possible in this world, whereas in other cases it is useful to consider solutions that are merely logical. Of course, nothing is absolute in this world: one can find very complex and highly esoteric problems in sciences that are not sufficiently understood by scientists to be classified as above (e.g., nobody possesses a sufficient understanding of the physical underpinnings of the modern M-theory). In such cases, the adequate problem classification becomes clear only when its solution is partially known.

2.3.4.2 Open and Closed Systems Revisited

The classification of the problem–solutions reviewed here also depends on whether the system Q has an open or a closed form. A closed-form system has its significant merits (by abstracting out irrelevant details, important patterns and even principles of Nature may be revealed). We have seen, however, that confusion can arise when one works under the restrictive conditions of a closed system environment and yet one behaves like it is an open system (Section 1.8.2). "There's always this tension in science that you want to control your variables and you want to know what it is you're studying. And yet you want to have what we call ecological validity, which is a fancy way to say it has to be like the real-world" (Byrne and Levitin 2007: 46).

Open systems are rather complex systems, i.e., their input parameters are incompletely known, reasoning goes beyond the strict application of formal logic, and uncertain influences and outside dependencies exist. It is a fact of life that very rarely can an open system be understood and described by means of a simple extrapolation from the properties of its basic components. Unlike pure mathematics, which limits itself to the solution of problems representing closed systems, in the vast majority of in situ situations one is concerned with the solution of problems representing open systems. According to Thomas A. Brody (1994: 125), in many cases outside dependencies can be more important than the inside features of the in situ system. When calculating the sea tide, e.g., one includes the positions of the sun and the moon, although they are very far, yet one does not consider the boats floating on that tide.

As we saw in Chapter 1, closed system problems are usually associated with curiosity-based (basic) research, whereas open system (in situ) problems are linked with action-based science. Serious difficulties arise when investigators are actually doing the former kind of research while falsely thinking they are doing the latter. There may be a substantial difference between the cognitive processes, basic skills, and thinking modes used in the solution of problems associated with closed systems and those used in the solution of problems linked to open systems. This situation parallels that observed in neuropsychological studies of the nature of problem-solving: empirical findings and theoretical concepts derived on the basis of simple closed systems (e.g., laboratory tasks) do not necessarily generalize to more complex, real-life problems (i.e., open systems). Unfortunately, this kind of valuable information is not available to many laboratory investigators, since they have isolated themselves within their institutional walls and sectoral silos. Furthermore, the processes underlying creative problem-solving differ across knowledge domains and across levels of expertise (Sternberg 1995). Accordingly, the IPS of an open-system may face significant challenges such as how to account for differences having to do with the way each discipline acquires and communicates knowledge. Physical sciences use mainly mathematical models to express conceptual, observational, and experimental findings. In humanities, there is little resort to mathematical formulas – chiefly, reliance is placed on analogy and metaphor. Briefly speaking, humanities emphasize emotion, sciences cognition, and technologies action.

2.4 Va, Pensiero, Sull' Ali Dorate[12]

In Giuseppe Verdi's famous opera *Nabucco*, the chorus of Hebrew slaves sings: "Va, pensiero, sull' ali dorate." It is a deeply human reaction that in critical moments of life (social, spiritual, professional; collective or intensely personal)

[12] "Fly, thought, on wings of gold" is a song from Giuseppe Verdi's famous opera *Nabucco* (or *Nebuchadnezzar*), which made its debut in 1842, and relates the Biblical story of the captivity of the Hebrews in Babylon during the sixth century BC.

the thoughts that fly are often the people's last resort. As a central element of scientific inquiry, thoughts that fly represent various expressions of creative imagination, among the most significant of which are thought experiments, mental images, and metaphors. Otherwise said, it is sometimes necessary to create a space for thought (Section 10.2.1) where excessive pragmatism and defensiveness can take a back seat while imagination and vision go beyond conventional wisdom to produce new ideas and radical innovations.

2.4.1 The Color That Fills in the Missing Data Gaps

A basic component of the IPS process is *imagination*, i.e., the human brain's ability to generate an extraordinary mental life. The importance of imagination can hardly be overemphasized. Relevant is the quote by Jim E. Baggot (2006: 17): "But there is obviously more to our mental lives than the passive impression of an external reality resulting from an ability to observe. Here lies the secret. With our highly developed minds we can also have imagination." Imagination allows conscious living and innovative dreaming while keeping open the access to reality. Imagination is the color that fills in the missing gaps in a data-based description of reality. Thought experiment and metaphor are two basic products of imagination.

The *thought experiment* (*gedankenexperiment*)[13] is an integral part of the IPS process. Thought experiments have been instrumental in the progress of science and beyond, and they constitute a powerful tool for understanding the world. It is indisputable that thought experiments are a common reasoning device in the context of both formal argumentation and in everyday life (Georgiou 2005). A thought experiment may take various forms that make it possible for the mind to discover things about Nature by sheer intellectual power, independent of empirical evidence (which may be unreliable). In this sense, thought experiments are formalizations of an intuitive grasp of an objective reality. They may also be viewed as arguments based on a proper mix of induction (empirical premises) and deduction (logical and scientific means). Thought experiments often employ closed-system reasoning that starts from empirically justified premises, abstracts out all irrelevant detail, and then uses deductive logic to yield valid conclusions.

Massimo Pigliucci (2006) considered Galileo's famous thought experiment that demonstrates (rather counterintuitively) that two objects of different weight must fall at the same speed. Contrary to popular belief, Galileo never actually climbed the leaning tower of Pisa to do this experiment – he didn't need to. He rather used the power of a thought experiment. Aristotelian physics would have predicted that a heavy body (H) would fall faster than a lighter one (L). But, Galileo's thought experiment goes, suppose we connect the two bodies by a string, thereby making the compound object $H + L$. Following Aristotelian physics, one would predict that

[13] The term was coined by Ernst Mach at the end of the nineteenth century to describe a specific method of enquiry used by professional scientists as a mental analog to physical experimentation.

$H + L$ should fall faster than H by itself because of the compound weight, i.e., $V_{H+L} > V_L$, where V denotes speed. However, the same logic can be used to claim that the compound body should fall at a slower pace than H because of the drag created by L, so that $V_{H+L} < V_L$. But this yields a contradiction, which means – by *reductio ad absurdum* – that really $V_H = V_L = V_{H+L}$. Neil Armstrong, the first man to set foot on the Moon, dramatically showed the whole world that Galileo's thought experiment was correct when he let go of a hammer and a feather in the absence of atmospheric friction while standing on the Earth's satellite, and they hit the Moon's surface at the same time. Such is the predictive power of thought experiments.

There are thought experiments that are abstract yet tied to physical entities that one can picture (like riding a beam of light). Einstein was well known for developing these kinds of thought experiments. His famous thought experiments concerning the completeness of quantum theory have led to serious debates among physicists that have greatly contributed to the advancement of the field. Other types of creative work may involve thought experiments with a strong visual aspect that contains images of processes and relationships rather than pictures of physical things. Also, thought experiments may rely on entities purely living in an equation world. In neurosciences, John Searle (2003) proposed an intriguing thought experiment, as follows: Imagined an agent in a locked room who receives written sentences in Chinese and uses an instruction manual to generate written sentences in Chinese. The relevant question this thought experiment attempts to address is whether the agent understands Chinese and, more broadly, whether a functionalist theory of mind is correct. Brain sciences benefit considerably from key questions posed by similar thought experiments. Many thinkers justifiably speculate that the well-designed implementation of thought experiments could have saved a lot of time, effort, and resources spent on real experiments.

2.4.2 The Essence of Metaphor

The reader may have noticed that in various parts of the preceding sections we have used the term "metaphor." This is because the use of literary metaphors constitutes a crucial element of theoretical IPS as discussed in this book. The great value of a good metaphor is that it implies an intuitive perception of the similarity in the dissimilar. The word has Greek roots: *meta* (μετά, meaning "beyond") and *pherein* (φέρειν, "to carry"), i.e., "to carry beyond." Generally, the essence of a *metaphor* is understanding and experiencing one kind of thing in terms of another (Lakoff and Johnson 2003: 5). A considerable part of human reasoning is metaphorical in nature.[14]

In our discussion of the links between science and art (Section 1.9.3), we already considered some intriguing metaphors. The kinds of metaphor people use vary from

[14] Naturally, metaphors are intimately connected with thought experiments.

simple linguistic expressions like “time is money” to thought representations of space–time as a container and a theater. Concerning the latter, the separate space–time metrical structure would be suitable to represent our common sense view of space as a container (within which all events take place) and time as an absolute entity (that registers the successive or simultaneous occurrences of these events); space and time exist independent of natural processes and laws, as a kind of a theater for the natural processes and laws to enact their drama. On the other hand, the basic idea underlying composite space–time is that, the theater (space–time continuum) is intimately linked to its actors (natural processes and laws) and cannot exist independent of them (Chapter 4). Many eminent scientists have emphasized the role of metaphors in scientific inquiry. One of them was Niels Bohr who argued that the intrinsic reality of entities in modern physics (e.g., electrons) was inaccessible to humans, in which case one can only hope to describe these entities in terms of metaphors. In an effort to emphasize the importance of the metaphor, Johann Wolfgang von Goethe famously uttered:

> Leave me at least the metaphor, so that I can express myself.

Under the circumstances, it is often a matter of human ingenuity to discover common elements between apparently very different domains of life. Robert Frost described the situation most vividly: “An idea is a feat of association, and the height of it is a good metaphor.” As another example of a metaphor with a powerful message, the readers may imagine an ichthyologist exploring the life of the ocean. The ichthyologist casts a net into the water and brings up a fishy assortment. Surveying the catch, the ichthyologist proceeds in the usual manner of a scientist to systematize what it reveals and arrives at two generalizations: No sea-creature is less than two inches long, and all sea-creatures have gills. These are both true of this catch, and the ichthyologist assumes tentatively that they will remain true however often one repeats it. In applying this metaphor, the catch stands for the body of knowledge that constitutes physical science, and the net for the sensory and intellectual equipment that one uses in obtaining it. The casting of the net corresponds to observation. Knowledge that has not or could not be obtained by observation is not admitted into physical science (Eddington 1967: 16).

2.5 Too Many Data–Too Little Sense, Mr. Grandgrind

Undoubtedly, careful and thoughtful data gathering is an essential ingredient of scientific inquiry. But human life has the nasty habit of transforming a creative activity into a trivial addiction. Considerable caution is then required so that data gathering does not turn into a mind-numbing process or an easy way out of an uncomfortable situation when one dries out of ideas. Lack of ideas is often the “kiss of death” as far as creative inquiry is concerned, since it is not only data that can determine the evolution of ideas, but also the ideas that can generate scientific and technological development.

2.5.1 The Datacentric Worldview and Its Perils

The problematic nature of *datacentrism* (data is the whole story and general conclusions fall directly out of particular data) is well understood. In a famous letter to Sir Karl Popper, dated November 9, 1935, Albert Einstein admitted that (Popper 1968: 458),

> Altogether I really do not at all like the now fashionable 'positivistic' tendency of clinging to what is observable . . . and I think that theory cannot be fabricated out of the results of observation . . . it can only be invented.

Many years later, several serious concerns still emerge about the collection of large amount of data in sciences without a deeper understanding of the underlying mechanisms and scientific principles. Adrian Berry notices that an increasing number of biologists realize that some areas of biology are dominated by mediocrities who are interested only in amassing vast quantities of information and who are hostile to new ideas (Berry 2007: 123). This view is echoed in Mary Midgley's thought (Midgley 2004: 3): "We do indeed sometimes think of science just as an immense store-cupboard of objective facts, unquestionable data about such things as measurements, temperatures and chemical composition. But a store-cupboard is not, in itself, very exciting. What makes science into something much grander and more interesting than this is the huge, ever-changing imaginative structure of ideas by which scientists contrive to connect, understand and interpret these facts." Particularly instructive is the case of the discovery of the DNA structure. One of the early investigators was Rosalind Franklin of King's College, London University. Using X-ray techniques, she had collected vast amounts of data. "Nevertheless, Franklin was unable to produce a meaningful synthesis of her data . . . disdaining a theoretical, less datacentric approach (which she evidently regarded as 'too flashy'), Franklin failed to see what she had before her" (Ogle 2007: 33). Franklin was probably unaware of Charles Darwin's confession made back in 1860 (Darwin and Seward 1903: 195):

> I have an old belief that a good observer really means a good theorist.

Beyond failing to make important discoveries, the one-sided, datacentric worldview can also cause other kinds of problems. Richard Feynman (1985) gives examples of fudging data not fitting the theory the investigators wanted to prove. "What is missing," Feynman says, is "utter scientific integrity," meaning "a kind of utter honesty, a kind of leaning over backwards," the duty "to report everything you think might make your conclusion invalid," and "giving details that could throw doubt on your interpretation."

Feynman's observation seems to apply in the case of recent studies at the aftermath of the WTC disaster (World Trade Center, New York City). In a series of reports (Jenkins 2006a, b), the EPA biochemist Cate Jenkins openly criticized the scientific validity of experimental results concerning the environmental pollution and health effects following the WTC collapse (Lioy et al. 2002; Yiin et al. 2004). Jenkins even claimed that the inconsistent reports about inhalant alkalinity were part of a cover up by government-funded scientists. The WTC dispute does not come as a surprise. As noted earlier, if it is not clear within which theoretical framework the experiments are performed, what exactly the experimental conditions are and how they could affect the results of the experiment, then disputable findings are obtained. One can find several examples in the history of science, some of which are rather famous. When Heinrich Hertz, e.g., was trying to prove the existence of radio waves, he did not think that the size of his laboratory was relevant to the experiment (but it was, because of wall echoes). But history teaches only those who are willing to learn, which does not seem to be the case with the WTC aftermath investigation. Alas, those who do not learn a lesson *from* history, history teaches a lesson *to* them, which seems to be the situation with the WTC investigation. This is yet another case of questionable experimental data analysis that could have been avoided if the agencies involved had invested thoughtfully on the integration of theoretical and experimental research, rather than relying on naïve data gathering from different sources. One ought to know that there is an irreducible tension in scientific inquiry: theory is not just the conceptual grounding of practice, it simultaneously accounts for why practice is ultimately doomed to failure. Hence, it is of utmost priority that the design of an *experimentum crucis* involves both the daring abstract thought of a theorist and the measurement skill of an experimentalist. Because experience has showed that when it comes to experimental data, one should be always reminded of Juvenal's old question: *Quis custodiet ipsos custodies*?[15] Before leaving this section, it is worth noticing that naïve induction can influence certain aspects of human culture, as well. For example, in the far past some ancestors of today's datacentrists had an accident after they saw a black crow or a black cat, and by generalizing on the basis of these accidental observations they concluded that black crows and cats bring bad luck. This is, indeed, how many superstitions are born.

2.5.2 Empty Cliches and the Illuminati

Supporters of the data-massaging and naive induction techniques often use clichés like "let the data speak for itself," or "the evidence does not lie."[16] These are rather empty clichés that have little to do with reality. As Arnold Hermann once noticed (Hermann 2004: 152–153),

> The tired adage that 'the evidence does not lie' has an impressive, even authoritarian sound, yet it is no less than a myth.

A clear warning against the naïve viewpoint came almost a 100 years ago in the insightful words of Friedrich Nietzsche (1910): "Everything that reaches consciousness is utterly and completely adjusted, simplified, schematized, interpreted." Nietzsche's view was shared by Kant, Darwin, Heisenberg, Bohr, Medawar, and

[15] "Who observes the observer?"; *Satirae*, VI, 347.

[16] Some people argue that "if one tortures the data long enough it will finally confess"; which is a cute way of saying that one can prove almost anything if one massages the data long enough.

many other eminent scientists and philosophers. Without underestimating the importance of thoughtful data gathering, mechanical reliance on the data should not be mistaken for objectivity. There are many substantive questions that cannot be answered in terms of data. Which is why, instead of "letting the data speak" and other naiveties, the following chapters focus on approaches that can integrate the language of the data with the language of daring abstract thought.

The ubiquitous *pseudo-practical* individual, petulant and critical, will protest against "sophisticated mathematical developments," "intellectually challenging theories," "abstract thinking," "contemplative analysis," and the like. Such peevish criticism is anything but practical, of course. By now, it is widely known that many of the simplistic techniques routinely used by the pseudo-practical "experts" lack methodological continuity and maturity, are not interrelated in a way that can offer a sound body of knowledge, and refer to situations with no scientific substance. Corporate science knows all too well that self-styled cliches like "bottom-line" and "no-nonsense practicality" (Goovaerts 1997: vii) are classic throwaway lines with a pleasant populist tinge that satisfy the "limited attention span" requirement. Yet the reasoning mode underlying such sound bites and pseudo-practical slogans is deeply unsatisfactory and inefficient, ignoring the basic principles of space–time change and consistency (physical and logical) between the different data sources. The same reasoning mode de-emphasizes the quality of knowledge in favor of satisfying the need of the "quick and dirty" solution, by which knowledge is encumbered and to which it is subordinate. Adding a small dose of culture into our discussion, the pseudo-practical approach reminds one of Mr. Grandgrind's teachings in Charles Dickens' novel *Hard Times*. Mr. Grandgrind taught his children large quantities of facts and statistics, but nothing that was remotely useful.

Why are pseudo-practical datacentrists so deluded? The delusion can be traced to their mistaking unprecedented access to information with the actual consumption of it. Moreover, these practitioners often confuse statistical issues with matters of scientific expertise (Section 9.4). This is largely due to their reliance on the beguiling "quick and dirty" practice, which considers it appropriate to criticize scholarly ideas that one does not fully grasp and to comment about a scientific work without reading it.[17] Some of the "bottom-line" techniques, while seemingly correct in formal terms, have serious methodological problems that undermine their validity. For example, if the ubiquitous "bottom-liners" had their way in astrophysics, one would be expected to obtain all useful scientific findings by looking at stars as finished products with no need to study the processes of star birth, formation, explosion, etc. In other words, the datacentrists who claim that they "let the data speak" are not being really honest. If they actually allow the data to speak, the data would tell an interesting story about the natural mechanisms that produced them, and answer questions about the physical processes represented by the numerical data values. But this is not the goal of the "bottom liners," who merely constraint the data to "quick and dirty" answers.

[17] In corporate geostatistics, e.g., this code has so much distorted the cognitive abilities of its practitioners, that they seem to have self-appoint themselves the role of "Illuminati."

As such, the pseudo-practical mindset is distinguished by its remarkable dullness, failing to reach the minds of those who think of something more than the appetites of the hour. This is what Lawrence R. Klein probably had in mind when he criticized the use of purely data-driven techniques, like time-series, in economics (Klein 1970): “The use of an estimated-structural model is clearly superior to any purely time-series analysis that has no explicit behavioral theory built into it.” It is safe to say that econometrics that is not based on substantive knowledge but is purely data-driven or simply assumed can be a risky business. When this sort of knowledge is not available, insistence on the use of these models does not make much sense. It claims to deliver what cannot be delivered under the circumstances, invites potentially serious misinterpretations of the actual phenomenon, and can do a disservice by diverting attention from the real issues. The Microsoft Chairman Bill Gates compared the role of deep thinking against the mechanization of things by saying that (Friedman 2007: 365): “You need to understand things in order to invent beyond them,” a view that directly opposes the naive “bottom line” model. Another well-known example is the mechanistic use of the copula technology. In the banking and insurance industry, e.g., the extensive yet arbitrary implementation of simplistic formulas based on Gaussian copulas has been linked to the 2008 financial meltdown (Salmon 2009). The irony is that many scholars tried to warn the financial practitioners about the serious dangers of using such simplistic yet substanceless formulas. Thomas Mikosch wrote about the copula concept: “I do appreciate that practitioners, in contrast to academic researchers, have to come up with solutions to their risk problems within deadlines and that ‘quick and dirty methods’ cannot always be avoided. Yet one may of course ask how much safety the banking and insurance industry (and maybe the rest of the world) really gains by using the copula concept” (Mikosch 2006a: 4). As a matter of fact, it comes as no surprise that the cemetery of applied science is well stocked with self-styled “bottom-line” and “no-nonsense practicality” techniques. Rather characteristic, in this regard, is the fate of geostatistics. Like Gabriel Garcia Marquez’s short story *Chronicle of a Death Foretold*, for several years geostatistics’ demise was widely known to be imminent but, nonetheless, those who cared about the field felt powerless to stop the demise,[18] which has been attributed to: (a) the complete domination of geostatistics by the corporate perspective, which led to its isolation from major theoretical developments in relevant fields of scientific research and rendered geostatistics unable to reflect on new concepts, abstract ideas, events, and relationships; (b) the lack of an intellectually credible representation, which allowed competing disciplines to hijack its message and claim ownership of much of its contents and scope; and (c) the inner alienation of geostatisticians themselves. The impression shared by most outside observers of the evolution of geostatistics has always been the same: This is a community of individuals who have little in common.

[18] It is, perhaps, a telling fact that more than half a century since its first appearance there is hardly any geostatistics department in American or European universities.

2.5.3 The Didactic Case of the Deutsche Physik

As noted earlier, one wonders why naïve empiricists blindly employ such ineffectual techniques based on an uninspiring mechanization that is fatal to thought and style. People suspicious of brute utilitarianism believe that many of the "bottom-liners" have left honest scientific inquiry behind in favor of the sound of the cash register. Other thinkers believe that this sad state of affairs is the consequence of a twofold cause: the naïve empiricists becoming increasingly intolerant to intellectual depth and creative thinking, and the agenda-driven commitment of the decadent elites to support this sort of anti-intellectual attitude.

The above attitude has a rather long history. Famous is the case, e.g., of the brutal assault of the experiment-driven *Deutsche Physik* clerkdom against theoretical physics, with the hidden agenda to harm prominent Jewish theorists. The ruling elite of experimental *Deutsche Physik* made a systematic attempt to completely eliminate from the face of the Earth some of the best theoretical physicists the world had ever seen, instead claiming the sole legitimacy of experimental physics that was supposed to faithfully collect the bare data and facts of Nature. Those who know twentieth century history can appreciate the grave consequences of this brutal anti-intellectualism. Any resemblance with today's events and situations is purely coincidental – or maybe is not.

2.5.4 The Glass and the Mirror

Once a child asked her father: "Father, what is the value of silver?" The man smiled, took a piece of common glass and carefully placed it in front of his daughter's eyes. Then he asked his daughter to tell him what she sees. The child looked through the piece of glass and said: "I see houses and trees, the sky, the sea, and other people." Then the father took the piece of glass and brushed its back with silver. After that he turned to his daughter and said: "Look again, now you can see nothing, except yourself."

Pseudo-practical minds unhesitantly chose the mirror, because its reflective surface satisfies their egocentrism and its silver brush represents their narrow-minded cupidity. By focusing on their reflection in the mirror, these minds avoid being challenged by critical thought, constructive criticism, differing perspectives, changing environments, new ideas, and other people's legitimate concerns. However, one would like to hope that instead of the mirror, many problem-solvers will choose the piece of clean glass, thus assuming the role of a critical thinker with an open-mind, genuine intellectual curiosity, interpenetration, creative imagination, and an innate ability for skepticism and self-criticism. This is the role of nonegocentric individuals (Section 1.11) who possess a sophisticated understanding of the issues needed to neither be the subject of manipulation (by corpomanagers, pseudopractical phonies, "bottom-line" fakes, charlatans, and the like) nor be deceived in things that really matter in life. *Ουκ επ' άρτω μόνο ζήσεται άνθρωπος*,[19] said Matthew, and if he was right, then truth cannot be abandoned to radical deconstructionism, and human existence cannot be limited to the satisfaction of lower needs.

2.6 Paradigm and Via Negativa

Being an expert in the technical literature is highly prized in many disciplines, as it should, whereas originality and creativity are looked on with suspicion, as they should not. In some cases this asymmetry reaches a critical point, which is why the philosopher of mind Colin McGinn chooses to view the situation as a sort of "graduate student mentality" that creates an environment in which "the people are less amusing, shallower, more one-dimensional." In a certain respect, the matter is summed-up succinctly in Einstein's well-known statement: "One of the definitions of insanity is to do the same thing over and over and expect a different result." What Einstein describes is a situation in which all kinds of techniques are employed and expensive experiments are devised, but if they are guided by the same perspective and function within the same inadequate conceptual framework, unsatisfactory results will be obtained again and again. No doubt, many of these results will be published in research journals – the sign of success being the treatment of research topics according to institutionally accepted methods. This is a situation largely favored by the clerkdom because it does not challenge the *status quo,* which means that, if necessary, a discipline must be ready to challenge the established paradigm.[20] To follow Blaise Pascal's advice, "after every truth one must be mindful of the opposite truth," one must find the courage to adopt a culture that is less "institutionalized" and "corporate," and more creative and open-minded, even if this implies considerable risk for one's professional career (promotion, social status, and prestige). But this is the price one has to pay when one lives in decadent times that try people's souls.

2.6.1 The Decisive Role of the Paradigm

To entrench into readers' minds how much the meaning of an entity depends on the context, let me risk a resort to religion. In a passage from the Gospel according to Luke, Jesus responds to a man as follows: "Why callest thou me good? None is good, save one, that is, God." Jesus' response is a classic case of the importance of considering an entity within the adequate context: as a God, Jesus is good, but as a human, He is bad.

[19] "A human being cannot live on bread alone;" *Matthew* 4:4.

[20] Section 1.7.3.2 used the term "paradigm" to describe a particular way of looking at things. Scientists develop hypotheses, solve problems, and advance understanding within the specified paradigm.

2.6.1.1 Goodnight Mr. Greenspan

Indeed, an agent's mode of thinking is a contextual matter that is closely associated with the agent's worldview or paradigm (including ultimate presumptions, theoretical background, social conditions, and traditional attitudes). If one (expert or layman) has any doubt about the crucial roles of worldview, paradigm, and mode of thinking, one can look at the testimony of the former Federal Reserve Chair Alan Greenspan at the U.S. Congress. The man, who is considered by many greatly responsible for the financial crisis of 2008, attributed his failure to regulate the financial markets to his inadequate worldview and reasoning mode. For many years the brief passage from Greenspan's testimony (Table 2.1) will remain a prime example of the grave consequences of a flawed worldview.

History repeats itself and has the habit to punish those who choose to ignore this fact. One may recall that President Herbert Hoover's main problem while fighting the Great Depression of 1929 was his flawed worldview. According to Kevin Baker's penetrating insight: "Farsighted as he [Hoover] was . . . he still could not convince himself to take the next step and accept that the basic economic tenets he had believed in all his life were discredited; that something wholly new was required . . . And it was this inability to radically alter his thinking that, ultimately, distinguished Hoover from Franklin Roosevelt. It was FDR, brought up with the entitled, patronizing worldview of a Hudson Valley aristocrat, who was able to overcome attachments to all classes, all theories" (Baker 2009: 34). Unfortunately for Hoover and for the Nation, he chose to espouse the pseudo-pragmatism of the clerkdom of its time and surrender to the usual interests of the powers-that-be rather than cut himself free of the dogmas of the past and realize the much needed new worldview. Which is what FDR finally did after him, thus enabling unprecedented advances in prosperity and quality of life.

Those who do not associate themselves with ahistoricism are able to learn from the fate of the great Byzantine empire. In the Byzantine worldview religion was the

Table 2.1 Passage from Alan Greenspan's testimony at the US Congress (October 23, 2008)

Rep. Henry Waxman: You had the authority to prevent irresponsible lending practices that led to the subprime mortgage crisis. You were advised to do so by many others. And now our whole economy is paying its price. Do you feel that your ideology pushed you to make decisions that you wish you had not made?

Alan Greenspan: Well, remember what an ideology is, is a conceptual framework with the way people deal with reality. Everyone has one. You have to – to exist, you need an ideology. The question is whether it is accurate or not. And what I'm saying to you is, yes, I found a flaw. I don't know how significant or permanent it is, but I've been very distressed by that fact.

Rep. Henry Waxman: You found a flaw in the reality . . .

Alan Greenspan: Flaw in the model that I perceived is the critical functioning structure that defines how the world works, so to speak.

Rep. Henry Waxman: In other words, you found that your view of the world, your ideology, was not right, it was not working?

Alan Greenspan: That's precisely the reason I was shocked, because I had been going for 40 years or more with very considerable evidence that it was working exceptionally well.

dominant force – natural science, geography and the like merely served as minor adjuncts to Biblical explanations of the world. There are several examples of theologians who tried to propose a new worldview that reconciled the physical world with Biblical concepts, but without success, due to the strong resistance of the ruling elites. As a result, Byzantium, unlike the fourteenth century Europe, did not acquire the new worldview (about the concept of time etc.). In this historical context, the birth of the Byzantine Renaissance never took place, despite the favorable conditions for such a birth during the period between tenth and twelfth centuries. In a sense, this was the beginning of the end for the empire.

2.6.1.2 Euclid's Contribution and Marx's Historical Observation

A problem and its solution are always considered within the boundaries of a paradigm; i.e., the problem and its solution may look very different when considered under the lights of different paradigms. The IPS approach may well turn out to be a meaning-dependent process, since the essence of its various concepts is determined by the chosen paradigm. The same biological data, e.g., can be interpreted differently, depending on the underlying evolutionist vs. creationist paradigm. The former may consider the data confirming the Darwinian view (species have involved over millions of years by means of natural selection and genetic variation), whereas the latter will regard the same data as confirming the creationist view (God simultaneously formed all the distinct species several thousands of years ago). The notion of a paradigm emerges in many different facets of life with intriguing consequences. Slowik (2007) suggests that an interesting parallelism can be drawn between a *sonata* and a paradigm. As with physical theories, one has to know and understand the relevant paradigm, classical sonata form, and to know what the relevant musical concepts (e.g., "theme" and "chord") really mean.

There should then be little doubt that the paradigm and mode of reasoning an investigator employs are crucial IPS components. In fact, they are often more important than any other solution component. The readers may find it interesting that, highly significant as it was, plane geometry was Euclid's second most important contribution. His most important contribution was the introduction of a way of thinking known as "axiomatic reasoning." An investigator's mode of reasoning can restrict the statement of the problem, the questions that can be asked about the problem, and the solutions that can be obtained. An improved reasoning mode may lead to a formulation of the problem that brings the investigator suddenly up against the deepest questions of knowledge. Get to the root of the problem, which can demonstrate the necessity of bringing multiple disciplines and crafts together. And reveal whether the necessary pieces (databases, techniques, etc.) are in place yet for a problem–solution to be possible. Incidentally, Karl Marx (1859) had made an interesting historical observation: "Mankind always takes up only such problems as it can solve, since closer examination will always show that the problem itself arises only when the material conditions for its solution are already present or at least in the course of formation."

2.6.1.3 The Role of Consciousness in Scientific Explanation

The reasoning mode is at the heart of the debate concerning the hierarchy of scientific explanation. The mode known as *reductionism*, e.g., seeks to reduce a problem to the underlying science (Section 2.2.6). In this way, psychological phenomena are to be explained in biological terms; biological phenomena, in turn, are considered in terms of chemistry; the latter is described using basic notions of atomic physics, whereas physics itself relies on solid empirical ground (Fig. 2.1a). With the advent of quantum physics, the classical hierarchy was challenged by the modern hierarchy that replaced "empirical facts" with "consciousness" (Fig. 2.1b). Remarkably, as early as 1932, John von Neuman (1932) showed that quantum mechanics makes inevitable the serious consideration of consciousness by physics. Since then, physics rests on the wavefunction collapse by agent's observation, which implies that one needs to add a somewhat "cloudy" consciousness at the base of the reductionist pyramid. Consciousness in an IPS setting is a notion that involves oneself within one's environmental context (Section 3.2.3ff).

Yet another crucial element of the reasoning mode is the serious consideration of rigorous testing of the solution obtained. A common solution testing is in terms of some kind of experimentation or observation campaign. Comparative analyses of theoretical derivations vs. experimental (observational) results are considered an integral part of the problem-solving process and have worked well in many studies (see, e.g., the works of Biryukov and Slekhova 1980; Will 1993; Bronnikov et al. 1996; Luini 1998; Dumin et al. 2000; Willer and Walker 2007). In some other cases, however, the comparative analysis was poorly conceived, ill-designed, and scientifically meaningless. Typical in this respect are environmental studies that emphasize a certain version of "brute force" engineering at the expense of basic science (e.g., Wilson 1993, 1994; Szilagyi and Parlange 1998; Zheng and Gorelick 2003). As a rule, the underlying comparative methodology of this kind of study is internally inconsistent and logically contradictory, whereas theory and experiment are noticeably incommensurable (Section 1.7.3.2): What is measured is not what is implied by the corresponding theory, the comparative setup is unable to translate the theoretical concepts into substantive experimental quantities, and there is no sufficient justification why the theoretical solution should be tested by means of its adequate fit to the specific experimental result and not the other way around. This is a process that routinely produces masterpieces of banality in which the underlying

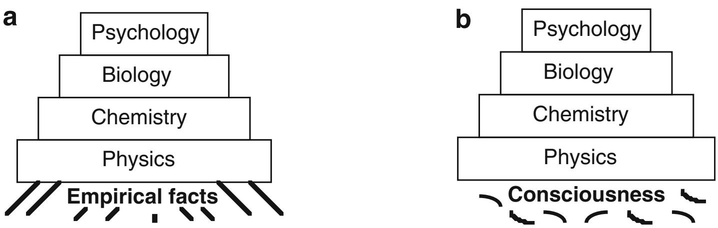

Fig. 2.1 Hierarchies of scientific explanation, (**a**) classical and (**b**) modern (reconstructed and modified from Rosenblum and Kuttner 2006)

reasoning is so meaningless and irrelevant that is probably best characterized by the phrase "saving fish from drowning."[21]

2.6.1.4 Critical and Creative Thinking Modes

The above considerations point to the real possibility, already hinted in Section 2.3.1.3, that certain problems are so perplexing and even intractable that their solution may require that the investigator's thinking mode extend beyond ordinary critical thinking into the domain of *creative* thinking. This is a serious development, since most mainstream problem–solution techniques (in terms of mathematics and statistics) have been built on the basis of the former rather than the latter mode of thinking.

Critical thinking is based on logical, structured, and systematic reasoning, which makes it a perfect tool for well-defined problems that require dissecting minute details. However, these same highly effective characteristics of critical thinking make it inadequate when a new perspective is needed to attack an otherwise intractable problem. This is because critical thinking operates within specific boundaries ("within the box," as is usually said) that often involves single-minded patterns of automatic thought. Creative thinking, on the other hand, requires that the agent thinks "outside the box" in order to find and assess the hidden assumptions that limit one's problem-solving abilities and generate new and unexpected solutions. The suggestion that during creative thinking certain parts of the brain linked to ordinary thinking are shut down is supported by experimental brain studies (e.g., a number of studies have shown that during creative thinking the agent's prefrontal cortex, the brain's reasoning and conscious control center, is not functioning; Limb and Braun 2008). Nonetheless, critical and creative modes are often interrelated: Creative thinking (a divergent process that generates all possible ideas) precedes critical reasoning (a convergent process that analyzes the ideas and evaluates their relative merits).

2.6.2 Learning Through Unlearning: Like Howling Bullets at Crux Moments

It was disappointing to discover in the 1990s that the sophisticated mathematics of diagrammatic theory and high-order perturbation analysis could not be used efficiently in the realistic study of flow and transport in subsurface media (e.g., Christakos et al. 1995), mainly because this is a poorly understood field that has suffered in the hands of outdated hydrogeology. In other words, one was dealing with a rather typical case of trying to use powerful mathematics to solve a physically ill-defined in situ problem. Because of misinterpreted natural heterogeneities,

[21] "Does anyone really care?" Probably no. In the corporatism era what counts is the ability to impress your colleagues not with your research findings but with your new luxury car. At least, if the car's technology is environment-friendly, the investment of the funding agency may not go completely astray.

unaccounted uncertainty sources across multiple scales, discredited measurement tools, and inadequate conceptual models that characterized the description of the phenomenon, it has led different authors to understand quite different things by it. The above episode shows that without ignoring the positive elements of an established paradigm, it is sometimes the case that the only road to new understanding is *via negativa*: much of learning is done through unlearning of what is established within the boundaries of the current paradigm, yet outdated (Schlesinger 1991).

Part of the difficulty of certain paradigms (like that of subsurface flow and transport above) is that they persist in talking about modern problems in an outmoded vocabulary. As Thomas Kuhn observed, the scientific establishment usually evaluates research solely on the basis of the potential contributions to the dominant paradigm; any ideas, proposals, or results that question the paradigm are rarely welcomed (Fuller 2006). In many cases involving novel phenomena and previously unobserved evidence, the solution of the associated problems is not simply a matter of established technical rules and mathematical proofs. What is needed is a new and clear view, which implies that an original thinker should reject the "conform-or-perish" approach of the cabals. Kurt Gödel, Ludwig Wittgenstein, and others have demonstrated that questions related to the nature of mathematics cannot be answered by means of mathematical constructs. Also, according to many investigators, an answer to the question of life cannot be obtained merely by logical and scientific means. Human minds have boundaries, and humans may not yet be advanced enough in their evolution to solve certain kinds of problems.

In view of the above considerations, an investigator should view IPS in a context that mimics the richness and interconnectedness of the knowledge sources available as well as the mental functions inherent in creative thinking. In other words, the reader may find that the following comments are worth examining: An issue of serious consideration is whether it actually constitutes a more realistic approach to invoke "optimal brains" (i.e., capable of searching for solutions that optimize meaningful epistemic goals) rather than to merely seek "optimal solutions" (in some ontic sense of "accuracy" and "speed," which may be inadequate under real-world conditions of uncertainty and incomplete knowledge). Any problem–solution is a mental process, and as such, it is based on human consciousness. The study of consciousness involves neuroscience, mathematics, psychology, philosophy, cognitive science, and computer engineering. Hence, it makes perfect sense that in setting up the appropriate paradigm the agent should fuse ideas and developments from these fields.

Often a problem–solution is based on new ideas that arrive like howling bullets at crux moments and split the face of the problem wide open, exposing concealed aspects and clarifying previously unexplained facts. On the one hand, the ideas may appear as precisely what was needed at their crucial point of entry. On the other hand, the ideas may appear at the present but with a sense of coming from the future. Whatever the case may be, it requires a certain level of mental finesse and self-cultivation on behalf of the investigator to appreciate the unique moments of innovation and creativity. Self-styled "practicality," overrated "common sense," and other fixations of single-minded individuals (Section 2.5) are completely inadequate and even irrelevant in such cases. In the following chapters, we turn our attention to the development of the conceptual Epibraimatics framework.

Chapter 3
Emergence of Epibraimatics

Deep theory is what is really useful, not the ephemeral usefulness of practical applications.

G. Chaitin

3.1 The Living Experience Outlook

Human brain is probably the most important and complex structure in the known world. In the words of the great ancient physician Hippocrates,

> All men should know that the brain, and the brain only, is responsible for and is the seat of all our joys and happiness; our pain and sadness; here is seated wisdom, understanding, and the knowledge of the difference between good and evil.

Two and a half millennia have passed since the "father of medicine" brought people's attention to the key role of the brain in human affairs. In the footsteps of Hippocrates, the workings of the brain continue to be at the center of twenty-first century cutting-edge research. *Epibraimatics* emerges as a synthesis of epistemic ideas and principles (*Epi*) from the broader field of brain sciences[1] (*brai*) with the goal of developing action-based mathematics (*matics*) for solving real-world problems under conditions of multisourced uncertainty and composite space–time change. Also, as noted earlier, Epibraimatics assigns considerable weight on the meaning of things. By re-examining the implications of these ideas in the broader IPS context, the above synthesis assigns a meaning to the problem–solution that is conceptually different than the conventional interpretation. In the same spirit, Epibraimatics seeks a relationship between objectivity and interpretivity involving a generative tension between the two. Hence, it is concerned about any factor that could threaten to topple the sensitive balance between

[1] This includes neurobiology, evolutionary biology neuropsychology, logic, and cognitive science.

G. Christakos, *Integrative Problem-Solving in a Time of Decadence*,
DOI 10.1007/978-90-481-9890-0_3,

objectivity and interpretivity to one side or the other (objective approaches to problem-solving do strip particular moments of phenomenal life of their particularity, and interpretive approaches are biased by the participation of the subject).

3.1.1 Epistemic Context and Deep Theory

As Albert Einstein has emphasized, the epistemic context is of utmost importance in scientific problem-solving (Einstein 1949: 684):

> Science without epistemology is – insofar as it is thinkable at all – primitive and muddled.

Echoing Einstein's observation concerning the value of philosophy in scientific inquiry, a few decades later Paul Feyerabend made an interesting remark: "The younger generation of physicists, the Feynmans, the Schwingers etc., may be very bright; they may be more intelligent than their predecessors, than Bohr, Einstein, Schrodinger, Boltzmann, Mach and so on. But they are uncivilized savages, they lack in philosophical depth." Feyerabend's remark signals a turning point in modern scientific thought: moving away from the prototype of a well-rounded scientist-intellectual to the narrowly specialized scientist-expert.

Philosophical thought is at the heart of Aristotle's classification between human agents of mere *sense-perception* (they *just* observe and record things but cannot establish correlations); agents of *experience* (they know *that* things are so, can establish correlations between them, and they make predictions based on unexplained correlations) who he held in higher regard than sense-perception agents; and agents of *theory* (they know *why* things are so, they explain and they make predictions based on general laws of Nature), who he held in higher regard than experience agents. Aristotle's almost three millennia old classification is at the roots of many developments as well as debates in contemporary science. In modern terms, one finds disciplines that are inhabited primarily by agents of theory, disciplines that are inhabited mainly by agents of experience, and disciplines that are inhabited by agents of sense-perception. Epibraimatics commits to the view that *deep theory* is really valuable in any field of serious inquiry. By "deep theory," it is not meant only symbolic patterns and formal manipulations, but primarily serious conceptual work, contextual understanding, and introspection that advance IPS in the real-world. Above all, theorists are *thinkers* playing with ideas rather than mere *specialists* manipulating symbols. The theory of Epibraimatics takes advantage of philosophy's depth and high practical value that bring the investigator's ultimate presumptions and basic methodology to critical scrutiny. It also recognizes that to solve a real-world problem is to enter into a relationship with it and generate a capacity for deeper insights. The result is a *living experience* of knowledge synthesis that accounts for "investigator-reality" associations rather than the mechanistic and ad hoc information processing characterizing many mainstream techniques, and rejects the ill-conceived pragmatism of "acting before thinking" that often has the result of people doing things in order to avoid thinking and discussing about them. It is unfortunate that the "acting before thinking" mindset dominates many facets of life in western societies nowadays. As Slavoj Zizek has observed, politicians quickly throw huge amounts of money at a problem instead of reflecting on how it came about. In scientific research, the same attitude has created a large number of government-funded laboratories with expensive equipment that produce plenty of trivial results, but in which little original thinking is generated.

As we saw in Section 1.3.1, the established forms of collective life (social structures, political agendas, educational systems, research policy, and administration) have a direct and immediate effect on the forms of thought that the individual investigator is able to consider, including what problems to study, and what theories, methods, techniques, and experiments to use. In the broad sense, therefore, an essential role of deep theory is to act as a wall of resistance to the crushing of free thought and human values by the Moloch of the PCU model (Section 1.5) and the brutality of the shadow epistemology (Section 1.4). The rigor and interpenetration of deep theory underlies the most fruitful critical thinking mode (Chapters 5 and 6), which can expose the logical and practical contradictions of pseudo-practical science, reveal the subterfuges of the established system (research administration, social environment, political influence, etc.) within which investigators are obliged to operate, and unmask the lies of the network of interlocking players that seek to control every sector of the society.

The knowledge synthesis of Epibraimatics does not seek to directly copy physical brain functions (like neural network techniques do, for example), but rather to develop mathematics that best fit *mental functions* associated with physical brain activities characterizing the agent's experience and abilities. In this sense, the synthesis focuses mainly on the "software" of the human brain rather than its "hardware." By assuring some level of compatibility between the IPS approach-in-the-abstract and the way a human agent actually learns and acts (expressed by the appropriate mental functions), one can perform a comparative assessment of the solution approach and the different strategies (learning, responding, etc.) the agent's brain uses. The comparison may show that an inefficient problem–solution approach is not compatible with an agent's mental functions; otherwise, it can show how to improve the agent's learning strategy. Rather than focusing on a single evolutionary characteristic (e.g., fitness), the synthesis involves a combination of evolutionary features and mental functions. Methodologically, Epibraimatics suggests a change of *direction*: While it is commonly acknowledged that a sound knowledge of physical sciences is a key prerequisite for a deeper understanding of life sciences, the opposite is also valid, i.e., the understanding of a physical system and the solution of relevant problems rely in a fundamental way on the agent's knowledge of the living realm of mental functions and brain activities.

3.1.2 Mathematical Formulation of Knowledge Synthesis

These considerations point toward the need for an adequate mathematical formulation of knowledge synthesis. Historically, there have been different settings within which the development and use of mathematics was considered. Various ancient cultures developed mathematics for purposes of measurement, accounting, construction, and commerce. In the sixth century BC, Pythagoras was the first to consider mathematics as an inherent element of Nature and as a means to understand all natural relationships and provide answers to some of Nature's mysteries (e.g., those associated with Astronomy). Several centuries later, Galileo suggested that the book of Nature was written in the language of mathematics and placed it in a context in which experimentation became a recognized method for discovering the facts of Nature. In the eighteenth century, Isaac Newton greatly advanced the relationship between mathematics and Nature by using the former to express the fundamental laws of the latter, and he also developed new fields of mathematics (differential and integral calculus).

This contextual role of mathematics was at the center of major developments in sciences for centuries to follow, including its more recent role in the description of physical mechanisms and basic processes in the living realm of biology. In Epibraimatics, mathematical modeling assumes a contextual role that emerges from the methodological change of direction mentioned here, according to which IPS should involve suitable mathematical formulations of basic mental functions. In particular, IPS modeling: (a) although it has a mathematical life of its own (in the technical sense), its development accounts for and is constrained by the conceptual framework and philosophical worldview embedded in Epibraimatics; (b) is a compromise between the technically efficient yet unrealistic objectivity of mainstream mathematics and the intellectually experienced epistemic principles linked to brain dynamics and their mental representations; and (c) is concerned with complex in situ systems under conditions of multisourced uncertainty and composite space–time dependency as well as with the thinking modes of the agents involved.

To achieve these goals, a prime concern of mathematical modeling is the pursuit of meaning in IPS rather than the mere creation of abstract formulations for their own sake. One objective would be to consider questions such as "When one uses mathematics, what does it tell one about the nature of the solution obtained?" "What is it for a mathematical symbol to have meaning?" "What requirements must a symbol satisfy if it is to be meaningful?" These are not rhetorical questions. Meaning does not reside in the mathematical symbols but in the way of thinking enveloping the symbols. Meaning is considered in various contexts: as a relationship between ontology and the truth, communicated through the use of language, or linking mental thoughts and things in the real-world. The pursuit of meaning may include the investigation of the psychological cognition level at which mathematical reasoning operates (Heyting 1971; Parkinson 1976; Lakoff and Nunez 2000).

3.1.3 Thinking "Outside the Box"

In light of these considerations, the IPS process reasons and connects diverse data sources, and draws from them new conclusions, so extending human understanding. As we saw in Chapter 2, in the Parmenidean tradition a problem–solution can only be a "truth-in-the-making" at best. The latter is an endeavor that requires innovation, creativity, and thinking "outside the box." Accordingly, Epibraimatics would view scientific inquiry as the ultimate adventure, which brings to mind Gregory Chaitin's confession: "I don't believe in spending years studying the work of others, years learning a complicated field before I can contribute a tiny little bit. I prefer to stride off in totally new directions, where imagination is, at least initially, much more important than technique, because the techniques have yet to be developed" (Chaitin 2005: xi). "We are no longer the nation that used to amaze the world with its visionary projects. We have become, instead, a nation whose politicians seem to compete over who can show the least vision, the least concern about the future and the greatest willingness to pander to short-term, narrow-minded selfishness," writes Paul Krugman in *The New York Times* (Oct 7, 2010). It leaves one a bitter taste thinking of the enormous number of good projects killed over the years. No visionary needs to look further than one's own backyard. For example, if a scientist writes a proposal to explore something new there is an almost 95% chance it will be rejected by the clerkdom-controlled funding agencies. Investigators are obliged to propose things that are almost sure to work, often in a trivial manner. That of course wipes out the chances of new stuff and mediocrity spreads. A doom and gloom state of affairs that is the trademark of decadent times. We will revisit this crucial matter in various parts of the book.

Before proceeding further with our discussion of the theory and its use in IPS, I suggest to briefly review some basic ideas and theses from brain and behavioral sciences that are, in my view, closely related to the development of a sound and innovative IPS approach. In this book, brain science is concerned with the rigorous study of the human brain and its mental functions by integrating (theoretical, computational, and experimental) knowledge from biology, cognitive sciences, and philosophy. Behavioral science, on the other hand, involves the systematic analysis and investigation of human behavior by synthesizing knowledge from the fields of psychology, sociology, and anthropology. The investigation is carried out through controlled and naturalistic experimental observations and rigorous theoretical formulations. Naturally, there are several areas where major scientific disciplines overlap considerably (neuropsychology, sociobiology, psychobiology, etc.).

3.2 The Background of Synthesis

Since Epibraimatics is a synthesis of concepts and principles from diverse fields of human inquiry, let us review some relevant aspects of these fields and consider their potential contribution in the development of a real-world IPS approach. Most of these fields are closely related to each other, whereas a few of them are still in their infancy – an exciting combination indeed. In its effort to create a unified and logically integrated framework of in situ problem-solving, Epibraimatics would benefit from certain elements (ideas, theories, and techniques) developed in the disciplines to be reviewed below, whereas it may reconsider, revise, or even reject certain other elements.

3.2.1 Evolutionary Theories of Knowledge

We start with a historical comment about the fundamental concept of *evolution*. In the view of certain scholars (Russell 1946; Osborn 1894; Workman and Reader 2004), Thales of Miletus (c. 624–545 BC) was the first who sought a naturalistic explanation of origins rather than attribute them to the gods. Thales clearly formulated a materialistic evolutionary concept of origins, which is why Vernon Blackmore and Andrew Page made this intriguing observation about Thales' thought (Blackmore and Page 1989: 10):

> If you prune away the fantastic, you are left with the ideas of evolution, perhaps even of natural selection-the evolutionary mechanism proposed by Darwin himself some 2,300 years later.

It will not be before the nineteenth century that an evolutionary theory was developed in a rigorous scientific way by Charles Darwin and others. In modern times, these early attempts have led to the creation of the *neo-Darwinian* worldview. Many attempts have been made to reconsider existing philosophical viewpoints in light of this worldview and to investigate how the latter can shed light on the origins and justification of human inquiry.

Evolutionary epistemology (or evolutionary theory of knowledge) is concerned with the study and understanding of knowledge through the use of evolutionary theory (Radnitzky and Bartley 1987).[2] According to evolutionary epistemology, the organs humans use to interact with the world – as well as the concepts, beliefs, and theories formed by these organs – have been shaped by biological evolution. Evolutionary epistemology sometimes makes stronger claims, such as the biological relativity of logic and the resulting evolutionary reasoning. Logical laws are seen as evolutionary propositions and the reasoning rules emerge from evolutionary processes. The reducibility thesis, e.g., suggests that a logical system is a branch of evolutionary biology, which is to claim that the foundations of the logical system are biological and logical rules are directly derivable from evolutionary principles (Cooper 2001). This strong perspective concerning the involvement of the brain's "hardware" in the development of logic systems has not been met without opposition (e.g., critics argue that evolution has nothing to do with logical or epistemic norms; Casebeer 2003). As is discussed by Donald T. Campbell (1974), attempts to place epistemology in an explicit evolutionary framework include Karl Popper's work on the evolutionary account of scientific growth, within which experimental *falsification* (Section 1.1.2; and Popper 1934) was viewed as the selectionist mechanism. Campbell presented a Darwinian account of the blind generation and selective retention of scientific theories over historical time. Richard Dawkins (1982) suggested a "theories-as-viruses" analogy, wherein the brain serves as a host for competing invaders that replicates by subsequently invading as-yet uninfected brains. Paul M. Churchland (2007) is critical of this analogy on the basis that a virus has physical characteristics (located in space–time, self-replication mechanisms), which is not the case with theory. Clifford A. Hooker's perspective of scientific inquiry as a biological phenomenon considers a nested hierarchy of regulatory mechanisms (Hooker 1995).

Closely related to evolutionary epistemology is the field of *evolutionary psychology* that is concerned with the study of human nature. Human nature is understood as the cumulative product of the experiences of our ancestors in the

[2] The reader may recall (Section 1.1.1) that, broadly speaking epistemology is a theory of knowledge that explores the structures and processes underlying human knowledge.

past and our individual experiences and environment during our own lifetime. It affects how we think, feel, and behave. In a nutshell, evolutionary psychology claims that the brain is a product of evolution just as any other bodily organ. Hence, one can gain a better understanding of the brain by examining the evolutionary pressures that shaped it (Buss 1989; Workman and Reader 2004). To properly understand brain activities, one must understand the properties of the environment in which the brain evolved (often referred to as the environment of evolutionary adaptedness). Human behavior is then a product both of the agent's human nature and the agent's unique individual experiences and environment. Jean Piaget (1950) was the first to propose a framework to assimilate biological and intellectual evolution, thus providing a much more naturalistic vision of information-bearing structures. The integration of concepts from evolutionary biology and cognitive psychology, as well as concepts that are important in adaptationist research, were discussed in the volume edited by Jerome H. Barkow, Leda Cosmides, and John Tooby, which for many experts marked the birth of modern evolutionary psychology (Barkow et al. 1995). The adaptive problems humans face and how the new field of evolutionary psychology encompasses all branches of psychology are discussed in David M. Buss' work (Buss 2003). Together with behavior genetics, evolutionary psychology is considered by many experts as the best theoretical framework available to understand the biological and evolutionary influences on human behavior (Miller and Kanazawa 2008).

In view of the above and similar studies, a reasonable conclusion is that evolutionary concepts (like adaptation, fitness, assimilation, and integration) generally play a central role in an agent's effort to gain knowledge of the real-world and to solve problems. As such, these concepts should be properly quantified for IPS purposes. First, it is is instructive to give a few examples of these concepts in action. Instincts are efficient and economical forms of adaptive behavior constructed on the basis of instructions built up in the past (Plotkin 1993). Other forms of adaptation involve feedback mental mechanisms that operate under the changing conditions of the physical world and respond to space–time relationships between events, processes, and objects. In the evolutionary context, fitness has been identified with subjective expected utility (Cooper 2001). Assimilation involves an epistemically evaluated cognitive synthesis of knowledge sources contributing to a scientifically adequate problem–solution, together with an assessment of the reliability of these sources and its incorporation in the solution (Christakos 2005). Integration in an evolutionary context implies that theories about a wide variety of natural phenomena, once properly construed, are compatible with each other and can be properly integrated to generate useful results (Hull 2006).

3.2.2 Cognition

Another field with conceptual contributions to the development of an IPS approach is *cognition*. This last term collectively refers to a variety of higher mental functions such as thinking, perceiving, imagining, speaking, planning, and acting (Dauwalder and Tschacher 2003; Reisberg 2005). Cognitive processes pertain to the action of knowing, whereas a cognitive system consists of mind-events, including perceptions, sensations, feelings, volitions, dispositions, thoughts, memories, and imagination – i.e., anything "present in the mind." In this sense, environment is the realm of physical events, signaled by perception and acted on through volitions. Perceptions and volitions (conations) constitute the cognitive system's means of communication with the environment (input and output). Thomas Kuhn (1962) proposed a radiative process by which different cognitive paradigms would evolve toward successful domination of a wide variety of cognitive niches. Subsequently, Imre Lakatos introduced a theory of intellectual evolution dynamics that closely accounted for the logical, sociological, and historical facts of scientific history (Lakatos and Musgrave 1970).

Cognitive *science* is concerned with the interdisciplinary study of cognition processes underlying the acquisition, analysis, and use of knowledge (O'Reilly and Munakata 2000). It combines evidence and methodology from diverse disciplines, including neuroscience, psychology, philosophy, anthropology, computer science, and linguistics (Harnish 2002). Cognitive neuroscience, e.g., unifies and overlaps with several disciplines, such as cognitive psychology, psychobiology, and neurobiology. As such, it is concerned with the scientific study of biological mechanisms of cognition, with emphasis on the neural substrates of mental functions and their behavioral manifestations. These functions and their manifestations are of considerable interest to Epibraimatics. Indeed, cognitive theory contends that problem–solutions may take the form of *algorithms* (rules that are not necessarily understood but can provide a solution) or *heuristics* (rules that are understood but do not always guarantee solutions). In other cases, solutions may be found through *insight* (a sudden awareness of relationships). Mental functions, which play a key role in Epibraimatics theory (Section 3.2.3ff), can be understood and described by quantitative methods: cognitive approaches are classified broadly as *symbolic* (using operations on symbols by means of explicit computational theories and models of mental – not brain – processes), *connectionist* (using artificial neural networks at the level of physical brain properties), and *dynamic* (using continuous systems in which all the elements are interrelated). The symbolic and dynamic approaches are used in Epibraimatics theory to quantify a set of basic postulates in an evolutionary setting (Section 3.5 and Chapter 7). For reasons to become clear later, I suggest that we make a key distinction between *descriptive* cognition that is about how things are (i.e., about things existing in the world independent of the human agent), and *prescriptive* cognition that is about the desired course of action (which is agent-dependent), about what needs to be done to satisfy certain desiderata. Epibraimatics considers carefully the fact that in recent years there is a shift of emphasis in neuroscientific inquiry from descriptive to prescriptive cognition (Goldberg 2005), as well as the consequences of prescriptive cognition in the development of an IPS approach.

Lastly, cognitive *technologies* are the means – instrumental and methodological – that contribute to the natural abilities of the mind to knowledge handling, thinking, and problem-solving. Such technologies include writing and designing, measurement and observation instruments, data collection tools, imaging procedures, and computational algorithms. Computers, e.g., are cognitive tools, since they extend the capabilities of the human mind. Paper and pencil are also cognitive tools (they enhance human memory by acting as a permanent record and mediate the formation of thought by serving as a scratchpad device). There is a qualitative difference, however, between these cognitive tools: The computer as a writing environment can become an active participant in the process (Chapter 9), whereas paper and pencil remain passive instruments. Demands and constraints presented by the technologies available can affect the development of cognitive processes and their effect on IPS. This is because cognitive processes are seen not merely as basic mind features but as a consequence of the interaction between cognitive brain structures and cognitive technologies (Pea 1985; Mioduser 2005).

3.2.3 Consciousness, Qualia, and Intentionality

What is also of interest to an IPS approach is that the agent's thought may be about an object (e.g., bacterium), about an idea (e.g., teleology), about a goal (e.g., maximizing agent's information), about a belief (e.g., science is the best approach to truth), or about a desire (e.g., stay healthy). As far as cognitive science is concerned, generating thoughts, "thinking," involves certain brain activities. According to an influential school of thought, electrical firings of millions of brain cells somehow produce one's private experience in terms of consciousness, qualia, and intentionality.[3] The last three are seen as *mental functions* linked to important activities that the brain carries out. In an Epibraimatics setting, a useful distinction between mind and brain might be to consider mind as dealing with the abstract representation of brain's functioning. In this way, one may associate theoretical functions such as the above with the mind, and material activities (control of body temperature and reflexes, regulation of heartbeat, etc.) with the brain.[4] In the same setting, it would be worth distinguishing between mental representations of the outside world (real-world phenomena) and mental representations (functions) associated with the inside world (brain activities). The former describe the way the agent conceives reality, whereas the latter predispose the agent to think, act, and behave in certain ways. Let us now examine each one of the above three mental functions in more detail.

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[3] How *exactly* this is done mostly remains a mystery, which has generated different views concerning the nature of the "brain–mind" relationship. While most views seem to agree that brain and mind go hand-in-hand, they differ about the specifics of the relationship (whether the mind somehow emerges from the brain, whether brain and mind are the same thing etc.).

[4] Although not exactly the same, the above distinction is probably close to that proposed by Marvin Minsky (1986: 287): "Minds are simply what brains do."

3.2.3.1 Human Consciousness and Qualia

Human *consciousness* is a combination of the abilities of language, thinking, understanding, experience, perspective, imagination, the self, intention, free will, and emotion, all in one short scene (Sternberg 2007). Agents are conscious human beings, in the sense that their mental functions (e.g., perception and thought) often have a phenomenal character, i.e., there is something it is like to be in them.[5] Self-consciousness is also a vital component in one's search for meaning and purpose in life. Since consciousness is an obvious prerequisite of a creative, non-mechanistic IPS approach, it is worth spending some time to obtain a better grasp of its main characteristics. For Epibraimatics, consciousness is a notion that involves oneself within one's surrounding context. As noted earlier, for some quantum physicists consciousness is the only possibility for measurement that is not itself subject to the wave-function of matter, which is why they argue that it constitutes the solution to the measurement problem. If consciousness is considered as the qualitative aspect of thought, neurons are believed to be the physical circuits of thought. Neurons are large, highly specialized cells of the nervous system whose function is to receive and transmit information in the form of electrical signals through the human body. From a biological viewpoint, networks of tiny interactions between brain neurons form the basis for consciousness. The networks are spread over the entire brain structure, but human ability for high-level mental functions, such as the thought processes involved in IPS, is centered in a specific part of the brain called cerebrum. As we shall see in Section 3.3, cerebrum functions and patterns have a considerable influence on the development and implementation of Epibraimatics ideas, postulates, and techniques. Many scientists and philosophers agree on the point that it is possible for consciousness to emerge from the physical structures of the brain. It is true that the individual brain neurons have none of the properties of what we consider to be consciousness, but by working together they can generate consciousness (Crick 1994).

In fact, there are many natural phenomena that are more than the sum of their parts. Chemical compounds such as salt, e.g., have very different properties than the elements they are made of. Table salt consists of sodium and chlorine; chlorine gas is a deadly poison, but salt (sodium chloride) is an essential nutrient. Section 1.8 brought to the readers' attention the methodological significance of the idea that the whole can be different than the sum of its parts. As Eliezer Sternberg (2007: 62) put it, "If non-living, almost invisible particles can be the building blocks of complex, living beings, it follows that non-conscious structures like neurons can be the building blocks of consciousness." There are, however, several events that currently escape biological explanation, such as how the conscious experience of tasting food occurs (how electrical signals cause an agent to taste olives; how do these signals cause cheese to taste bad to one agent and good to another). Although neurons are believed to be fundamental to how the brain activities, yet there are a number of open theoretical

[5] As it turns out, consciousness is a difficult concept to define. One reason is that its meaning transcends various disciplines, which makes it a major focus of any multidisciplinary approach.

issues concerning brain's function. Recent research in neuroscience hints that there are other physical structures in the brain that play an important role in the thought process: By changing an electrical signal as it travels, axons (long slender stems of neurons) may process and change information; blood can actively alter neuron signals, essentially regulating information flow in the brain; and astroglia (star-shaped glial cells) may play a basic role in brain plasticity.

Another aspect of the agent's private experience is *qualia* (the singular term is quale), which refers to the qualitative aspect of conscious experience. Although there is a debate whether they actually exist or not, qualia are considered by many experts to be the indescribable inner experiences an agent has. Such are personal experiences associated with hearing the sound of sea waves, smelling the distinctive scent of a flower, or feeling the wind blowing through one's hair. One may argue that can build a "machine" that can see. But this machine by no means will have the qualia of seeing. Hence, qualia are ineffable qualities separate from observable data. Humans perceive the world through a collection of qualia. For some mind experts, qualia are at the core of consciousness (Chalmers 2002) so that any attempt to understand the brain–mind relation would be impossible without incorporating qualia in its framework. Section 3.6.2 considers the qualia of phenomena involved in IPS in connection with their measurement and observation.

3.2.3.2 Concerning Intentionality

Intentionality is a representation of certain brain functions that has at least two meanings. In its simplest form, intentionality is the relationship between mental acts and the external world according to which agents are conscious "of" or "about" objects and states of affairs (ideas, beliefs, and desires) in the world. This is the sense in which the idea of intentionality was originally proposed by Franz Brentano, who distinguished mental from physical phenomena by observing that the former intentionally include an object within themselves (e.g., an agent thinks about this car or that house). Brentano was an influential philosopher and psychologist whose ideas were studied and modified by other philosophers, including Edmund Husserl[6] and Jean-Paul Sartre. In a psychological (rather than philosophical) sense, intentionality is a property of the mind by which a mental state has content and intentions in the ordinary language sense (goals, plans, or aims).[7] Epibraimatics considers intentionality in a sense that combines the "aboutness" and the "goal-oriented" meanings of the term. Agents are intentional beings, since they represent inside their brains what is going on in the real-world and on the basis of this representation they generate solutions to in situ problems.

[6] In a sense, Husserl replaced Descartes' motto "I think, therefore I am" with "I think about something, therefore I am," meaning that there is always an *object* of consciousness.

[7] When encountering the different meanings of "intentionality", one must clarify which one is intended.

In view of the above, consciousness itself may be viewed as fundamentally intentional (agent's mental states often have intentional content since they serve to represent the world). Husserl, Sartre, and others rejected the Cartesian view of human consciousness as something transcendent from reality (looking down on it) and, instead, they suggested the view that an agent exists within the world and makes sense of it only through consciousness. In a sense, the intentional stance is the strategy that assumes that humans are rational agents (their actions are determined by thoughtful consideration of their beliefs and desires) and interprets their behavior accordingly. Such a stance assumes that an agent sets goals, uses beliefs to achieve certain goals, and is smart enough to use the right ones in an appropriate way. We will revisit the concept of intentionality in various parts of the book. As it turns out, some form of quantifiable intentionality should be included in a general IPS framework.

3.2.4 Cybernetics

Another attempt in the study of human mind and behavior was the development of the field of *cybernetics*, which was the brainchild of the mathematician Norbert Wiener. He coined the term "cybernetics"[8] (Wiener 1948) to denote the study of *teleological* mechanisms (systems that embody goals). The concepts of information, feedback, and regulation were generalized from engineering applications to systems, including systems of living organisms, abstract intelligent processes, and language. Cybernetics combined the study of what in a human context is described as thinking and in engineering is known as control and communication. It suggested an approach based on a comparative study of the electrical circuits of the nervous system and those in the highly complex mechanical brains of electronic calculating machines, in an attempt to find common elements in the functioning of automatic machines and of the human nervous system, and to develop a theory that covers the entire field of control and communication in machines and living organisms (Helvey 1971). Key ideas of cybernetics are the negative feedback mechanism (through which conscious activities and brain operations function), and the teleological activity (the correlate of negative feedback systems by which signals from the goal can alter a system's behavior after it has been initiated, and the alterations making it possible for the system to reach the goal).

As far as Epibraimatics is concerned, a noticeable insight of early cybernetics is that a science of observed systems should not be divorced from a science of observing systems, since it is the agent who observes (von Foerster 1974). By shifting attention from observed systems (physical phenomena and attributes) to observing systems (language-oriented systems such as science), cybernetics generated useful system descriptions that included the observer, while maintaining a foundation in feedback, goals, and information (Umpleby 1990).

[8]"Cybernetics" comes from the Greek word *Κυβερνητική*, which means "the art of steering". Plato was the first who used the term to refer to government.

3.2.5 Epibraimatics' Synthesis

As will become obvious in the sequel, Epibraimatics seeks to assemble out of selected elements of the scientific fields reviewed above a unified, logically integrated, and quantifiable framework of real-world integrative problem-solving (IPS). A framework that systematically works out all of the revisions in existing theories, beliefs, and solution practices that such a synthesis requires. While IPS could benefit from certain elements of the theories and technologies described above, it does not necessarily share all their claims.

3.3 Brain as an Apparatus with Which We Think We Think

No doubt, the concepts of brain, mind, their relationships and differences are at the center of some of the most important human activities and concerns. At the same time, the human brain is the most complicated organization of matter ever known. Since not too much is actually known about the brain, a wide range of metaphors has been used to describe it: Among other things, the brain has been compared to a telegraph system, a telephone switchboard, and a digital computer. A prime difficulty in understanding brain is the underlying *circularity*. This circularity was nicely expressed in Ambrose Bierce's motto: "Brain is an apparatus with which we think we think." Readers should keep in mind that the discussion in the present section is directly related to the developments of the sections that follow.

3.3.1 A Bridge Between Nature and Humankind

For general purposes, one could approach the study of key IPS questions as a way of building a sort of a "bridge" between *mental states* (or *functions*) that are subjective and immaterial (thoughts, images, intentions, desires, and feelings) and *natural states* that are objective and material (observable physical processes extended in space–time, neuron firings and nerve fibers interacting with each other). The study of the relationship between Nature and humankind has a prominent place in Chinese philosophy. Early thinkers (second–fourth century BC), such as Zhuangzi, Mencius, and Dong Zhongshu perceived Nature as good and beautiful a priori (Chuang Tzu 1968; De Bary and Bloom 1999; Mencius 1990). Zhuangzi was preoccupied with aesthetic naturalism (overstating Nature's perfect beauty and ignoring humankind's active role) and Dong Zhongshu was concerned with mystical naturalism (reinforcing the heaven–human resemblance in order to project human affection into Nature), whereas Mencius favored pragmatic naturalism (stressing the mutual Nature–humankind independence and reciprocal interaction).

A major concern of the theory of knowledge is the actual nature of the relationship between subjective mental functions and the objective real-world. Indeed, humans view themselves as conscious, mindful, and rational agents in a world that science tells them that consists entirely of mindless and meaningless physical particles. Section 3.2.3 suggested that a connection between the mind and the brain is that the former deals with abstract mental functions (e.g., consciousness, intentionality, and teleology) linked to the activities the latter carries out (e.g., heartbeat regulation, body temperature, and reflex controls). Teleology is a mental function worth further investigation. Brain and neuropsychological sciences generally argue in favor of modeling effective behaviors and the cognitive processes behind them. Understanding how the mind deals with internal or external stimuli to result in behavior remains a major challenge for these sciences (Nichols and Newsome 1999). In many cases, to understand the relationship between a specific behavior and the brain, one needs to first understand the goal of that behavior. In response to this challenge, *human teleology* or *teleology of reason* argues that agents behave and act for the sake of reasons, purposes, and intentions rather than solely in response to the impulsions of efficient causation. This view is directly related to the notions of prescriptive cognition and intentionality discussed here. Consequently, human teleology is concerned with models of the mental functions by which knowledge and understanding are achieved, communicated, and used in real-world problem-solving. In this sense of things, the teleology of reason is an important element of Epibraimatics theory.

In today's world of conflicting ideologies and vested interests, it is important that human teleology be sharply distinguished from both the divine and the natural teleology. Divine teleology suggests that there is a divine plan reflected in world events. Natural teleology suggests the existence of some underlying mechanism that moves natural systems to an inevitable and discernible end (no deity is directing this mechanism, although humans may in some way facilitate the process). For example, while the Baconian empirical method and the Newtonian theoretical approach of scientific inquiry reject natural teleology, they do not contradict human teleology. It is noteworthy that a human teleologist is not committed to deity teleology. Friedrich Nietzsche, e.g., embraced human teleology even as he asserted that God is dead. In light of the above and similar considerations, teleologic thinking is at the heart of many scientific advances. For example, modern neurobiologists argue that to understand the relationship between human behavior and the biological brain, one must first comprehend the goal of that behavior (Glimcher 2004). Also, in behavioral ecology a working premise is that animals generate efficient solutions to the problems their environments present in order to maximize the rate at which their genes are propagated (Krebs and Davies 1991).

3.3.2 The Role of Philosophy

Contradictory facts concerning mind and brain, often referred to as "mind–brain" or "mind–body" problem, have tortured philosophical and scientific thinking for centuries (Carrier and Mittelstrass 1995; Lowe 2000; Dauwalder and Tschacher 2003;

Reisberg 2005; Stapp 2004). Naturally, several proposals have been considered in the literature. One of Kant's legacies was philosophy's focus on the "mind–world" relationship, what he referred to as the connection between subjective consciousness and the objective reality outside of consciousness. Yet, Kant did not consider the connection in *linguistic* terms since, for him, the connection should exist prior to language. But later philosophers (Frege, Russell, and Wittgenstein) started to look at language's role in the connection between mind and world and in mediating an agent's experience of the world. Some modern theories (see, e.g., Kandel 2010) argue that brain is a very complex computational device (constructing an agent's perception of the external world, fixing attention, and controlling actions), and that there is no such thing as mind apart from brain function. Instead, mind is a *set of operations* carried out by the brain (just as walking is another set of operations carried out by the agent's legs, etc.). This viewpoint seems to be subject to the brain paradox discussed in Section 1.6: The agent's brain (matter) uses brain's own set of operations to regard itself (i.e., brain creates that by means of which it is going to question, model, and comprehend itself). How is this possible, many ask, when the brain lacks an externalist perspective of itself? John Searle has summarized some of the relevant issues in terms of questions (Searle 2003: 13–14): How can a mechanical universe contain human agents that can represent the world to themselves? How can an essentially meaningless materialistic world contain meaning? Why social sciences have not given us insights into ourselves comparable to the insights that natural sciences have given us into the rest of Nature? What is the relation between the ordinary, commonsense explanations we accept of the way people behave and the scientific modes of explanation?

In view of these considerations, several schools of thought have been developed, including (but not limited to) the following: (a) mental functions are just physical brain states; (b) rejection of (a) on the basis that mental states have basic characteristics (e.g., intentionality or aboutness) that material functions cannot have; and (c) immaterial mental functions somehow emerge from material brain activities. The reader can easily notice that some of the above viewpoints are not completely contradictory. Indeed, all three viewpoints accept the experimental evidence that there is some complex relationship between brain activities and mental functions or states (e.g., local stimulation of certain brain cells near the back of the head can generate visual experiences). But viewpoint (b) categorically rejects the assertion of viewpoint (a) that brain and mind are the same thing (e.g., intentionality is a property of the immaterial mind but not of the material brain). It notices that mental states, like beliefs and thoughts, point beyond themselves and are always *about* something (one's belief that drives a car is *about* the car, one's feeling that loves a person is *about* the person, and one's thought that a painting is beautiful is *about* the painting). Concerning viewpoint (c), an influential school of thought seems to suggest that the relationship between the "mind" and the many millions of cells that constitute the "body" is one in which the "mind," although influenced by the "body," normally controls the "body." This control is not strictly deterministic; instead, it contains a significant amount of uncertainty (e.g., the body may react decisively, if the mind disregards its needs). Perhaps not surprisingly, the matter goes beyond science and philosophy to the domain of arts. The master artist Alexander G. Weygers wrote: “Learning to master the hand craft is one thing, but learning how to use the mind that guides the hand to make things is another” (Weygers 2002: 9).

3.4 If Plato Were Alive

Most historians and science scholars find it remarkable that major ancient civilizations, such as the Egyptian, did not consider the brain as a significant human organ, which is why it was unceremoniously removed during mummification (Gibb 2007). The ancient physician Alkmaeon was among the first to recognize the significance of the brain circa 450 BC. For a variety of reasons discussed in the history of science literature, a long period of inactivity followed. Significant progress in brain research was made by Leonardo da Vinci and other scholars of the Renaissance era. Major achievements were made during the following centuries. Today, neuroscience and related fields are admittedly among the most active areas of research (Gazzaniga 2000a, b; Edelman 2006; Gazzaniga and Heatherton 2006). As a matter of fact, it has been said that,

> If Plato were alive he would be working in a neuroscience laboratory.

In view of new and substantial findings in neuroscience, psychology, cognitive science, and philosophy, old questions about scientific inquiry and problem-solving have taken on a new salience. It is within this environment that Epibraimatics theory and the IPS approach emerge.

3.4.1 IPS That Fits Mental Functions

Brain research has revealed important information about the special activities of the various parts of the brain, their evolutionary characteristics, and their significance. Part of this information reinforces the validity of what were previously viewed as mere conjectures, whereas some other findings point to new and occasionally surprising directions worthy of further investigation. One of the most intriguing findings is that the problems solved by human intelligence are simplicity itself in comparison to the problems solved by evolution (Gellatly and Zarate 2003: 54). On occasion, evolution seems to ignore physical laws invented by humans. As has been observed, e.g., aerodynamically the bumblebee should not be able to fly, but the bumblebee does not know that so it goes on flying anyway. The above considerations may require revisiting the way the human brain is organized, especially focusing on how mental functions and behavioral patterns fit in with scientific evidence and quantitative thinking, and using this knowledge as an inspiration to continuously improve one’s IPS reasoning under in situ uncertainty conditions. An

Epibraimatics premise is that IPS reasoning would be implemented more efficiently by the human brain than the conventional problem-solving approaches, since the former is designed to fit mental functions and behavioral patterns shaped during many years of evolutionary pressures.

3.4.2 Quantitative Representation of Mental Functions

At this point, it may be instructive to review certain elements of the brain architecture and point out their potential significance in the IPS context. Studying the various parts of the brain and their corresponding activities can help comprehend how the brain controls thought and action. Brain activities are *localized* and *consequential*: Separate activities at each part of the brain (electrical firing of billions of neurons and their interactions) give rise to the corresponding agent's experiences and abilities. Some of these experiences and abilities are conscious mental functions (e.g., planning, reasoning, and decision), whereas some others are unconscious (bodily movements, favoring certain tastes, and experiencing emotional conditions).

In the previous sections, we saw that understanding of the relationship between brain activities and mental functions is of paramount importance. And as such, it is a highly controversial matter. While one school of thought claims that brain and mind are the same thing (e.g., mental functions, like thoughts and emotions, are material events in the brain), another school of thought argues that mental functions are nonphysical entities that somehow emerge from the physical brain structure (e.g., brain neurons that have none of the properties of consciousness can club together to generate consciousness). Although these different viewpoints are of great interest in the brain–mind debate, they do not directly affect IPS. Therefore, Epibraimatics focuses on the significance of mental functions per se rather than on open issues, such as the exact origins (physical or otherwise) of the mental functions, whether the mind is something different from the brain (although connected to it) or it is the brain itself, etc.

It is postulated that a careful consideration and quantitative expression of mental functions could enable an agent derive sound problem–solutions by predisposing one to think or act in certain ways. Schematically, the process may be represented as follows:

$$\left.\begin{matrix} Localized\ brain \\ activities \end{matrix}\right\} \rightarrow \left.\begin{matrix} Mental \\ functions \end{matrix}\right\} \rightarrow Problem - Solution. \tag{3.1}$$

The fundamental representation (3.1) puts considerable emphasis on mental functions and their key role in IPS. This emphasis is supported by the facts: Jerry Fodor (1975, 1998) has pointed out that the basic elements of cognitive activities (like problem-solving, decision-making, and theoretical thinking) are all mental functions.[9] Eq. (3.1) presupposes a *rational* agent in the sense described by Robert Hanna (2006): a conscious, rule-following, intentional (possessing definite capabilities for entity-directed cognition and purposive action), volitional (possessing a capability for willing), self-assessing, reasons-giving, and reflectively self-conscious individual. Hence, a prime concern of Eq. (3.1) is to investigate what a problem–solution could possibly learn from the mental functions, rather than directly from the material brain activities or the precise way these activities give rise to mental functions (this way is to a large extent unknown – understanding the complex biochemistry that turns chemical and electrical energies into memories, thoughts, and feelings has long been one of the greatest challenges of brain sciences). Although certain mental functions are examined in this book (e.g., intentionality, teleology, and adaptation), it is possible that other functions could be also useful under different circumstances and for solving other kinds of problems. The reader should keep in mind that this is a book of thoughts and suggestions rather than definite answers.

3.4.3 Brain Parts and Their Activities

I am not a brain scientist; I am simply one of those people who appreciate the importance of the field in a broad sense. This being the case, my technical review of brain matters relies on the expertise of others. As noted earlier, my intention is to interpret and synthesize this technical knowledge with knowledge from other fields of human inquiry in the context of Eq. (3.1) in order to develop an IPS framework for natural systems under conditions of in situ uncertainty and composite space–time dependency. There are four main parts of the brain (De Burgh 2007): the *cerebrum* (right and left hemispheres), the *cerebellum*, the *diencephalons* (thalamus and hypothalamus), and the *brain stem*. Each of these four parts is involved in different activities (Bianchi 1922; Brickner 1936; Ferrier 1876; Anderson 1983; Cohen 2000). The cerebrum, in particular, consists of the right and left hemisphere, each of which is further divided into four lobes: the frontal lobe, the parietal lobe, the occipital lobe, and the temporal lobe. Neurons throughout the human body receive sensory information from the outside world, which they transmit to the cerebrum. The cerebrum processes this information to form a meaningful image of reality in terms of mental functions and, subsequently, organizes the behavior by which it responds. Appropriate response patterns (e.g., suggesting a specific problem–solution to reduce a company's budget, or reaching a legal compromise in a court case) are stored in various organizations of neurons. The surface of the cerebrum is called the *cortex*, and

[9] Some thinkers draw a parallel between the mind-brain duality and the wave-particle duality: Just as in quantum physics one talks of a wave of information (that has a probability shape) about a particle's physical characteristics, so in cognitive science one talks of a mental function of information (probabilistically interpreted) about the brain's physical activities. Both the wave function and the mental function, unless they are registered in consciousness, are without significance.

Table 3.1 Main activities of the left and right brain hemispheres

Left brain hemisphere	Right brain hemisphere
Reasons sequentially	Reasons holistically
Analyzes information	Synthesizes the big picture
Grasps the details	Recognizes patterns
Excels in strictly logical activities (formalizations–deductions–inductions)	Accounts for complementary activities (emotions–intentions–metaphors)
Handles what is said or written	Focuses on how it is said or written
Identifies categories	Identifies relationships
Specializes in text	Specializes in context

is the area that processes most of the brain's information. Different regions of the cortex have distinct and highly specialized activities (Warren and Abert 1964; Perecman 1987; Frith et al. 1991; Miller 1999; Cohen 2000). For IPS purposes, initially the focus is on the complementary activities of the two brain hemispheres and the reasoning functions of the front of the cerebral cortex (prefrontal cortex). This does not imply that activities in other brain parts (e.g., hippocampus[10]) do not play important roles in human understanding. Rather, there is significant evidence that cerebrum functions can offer valuable insight to the goal of developing an IPS approach.

The two brain hemispheres perform different activities, as summarized in Table 3.1. Some of these activities have been studied in a teaching context by Linda Williams (1986). These activities reveal a *hemispheric complementarity*, in which the left hemisphere of the brain gives rise to the so-called left-directed thinking and life attitude (sequential, literal, functional, textual, and analytic), whereas the right hemisphere of the brain gives rise to the so-called right-directed thinking and life attitude, simultaneous, metaphorical, aesthetic, contextual, and synthetic (Gazzaniga 1998, 2000a, b; Ivry and Robertson 1998; Wolford et al. 2000). The left hemisphere played a fundamental role in the Information Age, whereas the right hemisphere is the focus of the emerging Conceptual Age. Concerning this distinction, an increasing number of thinkers argue that the world is (Pink 2005: 1–2) "moving from an economy and a society built on the logical, linear, computer-like capabilities of the Information Age to an economy and a society built on the inventive, empathic, big-picture capabilities of what's rising in its place, the Conceptual Age." Epibraimatics appreciates the significance of hemispheric complementarity in developing a meaningful IPS approach, and seeks to develop a rigorous mathematical framework that involves the integration of mental functions associated with both brain hemispheres. This is a two-sided mind framework that acknowledges that there are real-world problems the solution of which requires the blending of the *analytical* processing of the left brain hemisphere (functioning in a step-by-step manner with the ability to discriminate the relevant features and reduce the whole to meaningful parts) and the *synthetic* processing of the right hemisphere (functioning in a parallel manner with the ability to integrate

[10] Located inside the medial temporal lobe of the cerebral cortex and, hence, is part of the forebrain. Hippocampus plays a major role in short-term memory and spatial navigation.

component parts, organize them into a whole, seeking patterns and *gestalts*[11]). Hemispheric complementarity is in line with experimental findings suggesting that individual hemispheres often are not dedicated to a single behavior but are rather specialized for particular features of that behavior. Brain has been evolved so that the two hemispheres work closely together and hemispheric control switches rapidly from one hemisphere to another. The development of IPS postulates (Section 3.5 below) seeks to account (*inter alia*) for mental functions linked to complementary brain features.

3.4.4 Learning from Brain Activities

Neuroscientific research has shown that the prefrontal cortex is at the center of cognitive development, it powers conscious thought, and it is the seat of high-level reasoning (Fuster 1980; Boller and Grafman 1994). Tasks the prefrontal cortex takes on include judgment, choice, planning, motivation, memory, language, and emotional reactions, and it is in charge of making plans for solving a variety of real-world problems (Passingham 1993; Ward 2006) Previous knowledge is accumulated within the prefrontal cortex so that the agent is prepared to deal with complex problems, at least at an initial (prior) stage (Smith and Jonides 1999). Hemispheric specialization in the frontal lobes is hypothesized to exist for cognitive activities in response to ongoing events. Prefrontal cortex is the source of motivation, i.e., compelling the agent to pursue rewarding goals. In particular, some researchers (e.g., Aihara et al. 2003) have hypothesized that there exist two functionally and neurally distinct cognitive selection mechanisms involving the lobes: those linked to processing based on internal representations (context-dependent reasoning) and those associated with exploratory processing of novel cognitive situations (context-independent reasoning). Extreme context-dependent and context-independent response selection biases have been linked to the left and right frontal systems, respectively (Podell et al. 1995).

It is rather widely accepted among experts that the front of the frontal lobes controls behavior, planning, and social skills, whereas the sides control thinking. An agent is born with certain built-in behaviors and responses, a situation called *phylogenetic memory* (memory programmed into the nervous system of a species). This is not a memory due to a learning process, but one developed through natural selection and evolution. The subsequent growth and maturing of the frontal lobes closely parallels the development of an agent's view of the surrounding world and its many features (physical, social, etc.). An agent builds a mental *model* of the surrounding environment and responds to this model, rather than directly to the environment. The stages passed through as an agent develops such a model were

[11]"Gestalt" is a structure, configuration or pattern of physical, biological or psychological phenomena so integrated as to constitute a functional unit with properties not derivable by the summation of its parts.

originally studied by Jean Piaget (1930). During each stage (which takes place around a particular age), the agent uses the model currently available to understand the world. If a new experience fits with the current model, it is properly *assimilated*. If it does not, the model may be *adapted* to a lesser or larger extent. As a result, the agent's mental model of the world becomes improved at each stage. The adequate quantification of the notions of model, assimilation and adaptation, play a key role in the development of the IPS approach (e.g., assimilation is linked to the quantitative integration of knowledge bases that are internally consistent and most relevant to the problem at hand, and adaptation is connected with solution-updating in light of evidential developments; Section 7.3).

Section 3.2.2 pointed out an important distinction between descriptive and prescriptive cognition. As it turns out, the frontal lobe is closely associated with prescriptive cognition but has little to do with descriptive cognition. In recent years, there is a shift of emphasis in neuroscientific inquiry from descriptive to prescriptive cognition performed by the mechanisms of the frontal lobe. For one thing, evolution seems to focus on prescriptive rather than descriptive cognition aspects. Elkhonon Goldberg (2005: 158) maintained that "the evolutionary pressures that have shaped our brain and our body were directed to enhancing our survival and not our ability to establish the ultimate truth, even though the latter would be a nice facilitator of the former." Similar is the view of the evolutionary psychologist Steven Pinker, who believes that our brains are made for fitness rather than truth. In general, according to these studies, organisms produce behaviors of a prescriptive character, such as the goal of maximizing fitness (in some sense) within their environments (Glimcher 2004). Evolutionary arguments are worth examining by an IPS approach that is action-based and is built on postulates concerning mental functions. The Epibraimatics proposal is that as the human evolution process takes a more advanced form, there is nothing in it that excludes prescriptive behaviors at a higher sophistication level seeking to secure a balanced development of survival and search for meaning for the sake of human existence as their ultimate telos.

3.5 Fundamental IPS Postulates

An IPS approach could be viewed and assessed, to a certain extent, in terms of the scientific paradigm of evolution. Human mind is a powerful IPS tool, one that in definite ways distinguishes humans from other animals. According to the fundamental Eq. (3.1), a rational agent is concerned with the development of a sound mental framework and the resulting efficient tools that can formulate the in situ problem in a multiperspective, multithematic, and open-system manner, and derive its solution accordingly. To achieve this goal, Epibraimatics proposes a set of IPS postulates that allow an operational representation of theoretical mental functions,[12] and then searches for solutions that optimize these functions seeking the big

[12] Such as intentionality, teleology, and adaptation (Klahr 2000; Harnish2002; and Section 3.2.3).

picture and improving understanding. Correspondingly, one more stage is added to Eq. (3.1) as follows:

$$\left.\begin{array}{r}Localized\ \ brain\\ activities\end{array}\right\}\rightarrow\left.\begin{array}{r}Mental\\ functions\end{array}\right\}\rightarrow\left.\begin{array}{r}Fundamental\\ postulates\end{array}\right\}$$
$$\rightarrow Problem - Solution. \tag{3.2}$$

In the setting of Eq. (3.2), the IPS approach focuses mainly on the "software" of the human brain rather than its "hardware"[13]: The approach does not seek to copy physical brain activities (how neurons interact, cell processes, etc.) but to develop theories and tools that best fit important mental functions linked to these activities. The postulates are first presented and then an attempt is made to explore how they could establish, in collaboration with Eq. (3.2), a useful conceptual IPS framework.[14] Following this process, some readers may be convinced immediately, some others would need more time to decide, and yet another group of readers may remain unpersuaded. Whatever the outcome, the important thing is that the process helps improve one's thinking about the matter and/or raises some new questions. From a neuroscientific perspective, the IPS postulates can be seen as theoretical representations of certain aspects of established brain activity, which itself is a product of evolution, hence they may be called "evolutionary" postulates. The four postulates are as follows:

Complementarity postulate (CoP): A mental model of the real-world system consists of various complementary possibilities (realizations) representing the multisourced uncertainty and composite space–time variability of the system as conceived by the agent.

Classification postulate (CP): Knowledge becomes available to the agent in two major forms, *general* or *core* knowledge (gathered during many years of human effort and stored mostly in the left brain hemisphere), and *specificatory* or *site-specific* knowledge (recent data concerning the specific situation and accumulated mainly at the right hemisphere).

Teleologic postulate (TP): An evolutionary mind feature is seeking teleologic reasoning models conditioned by the core knowledge of CP. A mental model, e.g., expressing goals in information terms constitutes a prime intentionality feature bestowed to humans by Nature.

Adaptation postulate (AP): As part of the synthetic reasoning process (acquiring and assimilating knowledge), the fitness of the model obtained by TP is assessed and updated in light of the specificatory knowledge of the CP, and issues a internal consistency are addressed.

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[13] A metaphor may be useful here. A computer can be described in two distinct yet mutually compatible ways (Cosmides et al. 1992): one way describes the computer hardware, i.e. how the computer components function and interact (electrons flowing through circuits, chip functions etc.); another way describes the software, i.e. programs that the system runs (input information, data representations and structures, algorithms that transform information etc.).

[14] Chapter 7 will deal with the corresponding quantitative operators.

At the heart of the IPS postulates is the realization that meaning and knowledge emerge from the agent's imaginative ability to create abstract representations and the subsequent generalizations. Concerning their underlying structure (philosophical, logical, and psychological), the postulates are well suited to identify and account for patterns of values, mental functions, and behavioral interrelations so that they can be put into testable implementation. In view of the evolutionary aspect discussed here, a noticeable feature of the IPS postulates is their association with the search for the best course of action (what possible realizations to consider before the event, how to classify knowledge, which desiderata a meaningful problem–solution should satisfy, etc.) rather than about strictly the "true" nature of things in a mechanistic narrow-sense. In the Darwinian vision, evolution created an agent's mind to survive in an environment, that is, the mind is about the environment. Correspondingly, IPS should not be based on a single characteristic but on the appropriate combination of various features associated with evolutionary dynamics and mental functions (recent and distant). This is not a state of *non plus ultra*.[15] The reader may want to keep in mind that, since the choice of mental functions to use in Eq. (3.2) is not necessarily unique, the same would be true for the corresponding set of IPS postulates. Hence, it is consistent with the broader Epibraimatics' perspective that one or more of the above postulates might be replaced in the future by equally sound or even better alternatives. We proceed with the discussion of the postulates and their potential implication in the IPS process.

3.5.1 Concerning the CoP

The justification of the CoP involves mental representations of observed brain functions and conscious human behavior associated with the problem at hand. As we saw in a previous section, among the prime activities of the frontal lobes is the ability to recognize future consequences resulting from current actions, determine similarities and differences between entities (events, objects, or phenomena), and to choose between possible responses guided by internal states or intentions (Frith et al. 1991; Miller and Cohen 2001). Experimental evidence shows that in order to perform this critical function, the frontal lobes do not construct a single reality but consider many future possibilities of the currently unobserved phenomenon and plan accordingly (Gilbert 2005). The conscious consideration of multiple realizations in space–time is an intentional action by means of which the brain explores the real-world and attempts to anticipate (predict) future events. The brain seems to control the number of realizations according to the conscious level of incomplete knowledge and degree of space–time uncertainty (Miceli and Castelfranchi 2002). From an evolutionary perspective, brain's ability to explore multiple realizations is necessary for an agent to succeed in an uncertain environment. It is often a matter of survival that the number of realizations considered by the brain is sufficient, and

[15] The ultimate best thing that could possibly happen, the acme, the highest stage of development.

one can even imagine a probability distribution that generally assigns different likelihoods to each realization. Jeff Hawkins (2004) is quite clear in that these realizations should be viewed as tentative predictions that the brain makes in a parallel fashion based on stored memories and sense data. Brain neurons involved in the generation of these predictions become active before any sensory data are received. When the latter arrive, they are compared with the former.

In the Epibraimatics context, the above functions of the brain are expressed in terms of the CoP, which implies that the solution of a problem could not be limited to a single yet unknown or unknowable objective reality but consider several potentialities depending on the epistemic state of the agent and the in situ conditions. CoP's representation of brain's flexibility (that allows it to explore and efficiently process multiple possibilities of unobserved phenomena under conditions of uncertainty) is a welcomed feature. Furthermore, the improvement of the CoP within the IPS framework relies on the adequate quantitative modeling of the multiple realizations considered by the brain. As we shall see in the following chapters, the CoP modeling involves the mathematical theory of *spatiotemporal random fields* (Chapter 5). This theory enables IPS to go beyond the unrealistic expectation associated with the construction of a single reality and allows for several realizations (potentialities) that are logically and physically plausible under conditions of in situ uncertainty. Different probabilities are assigned to each realization depending on the (incomplete) understanding of the phenomenon. The realization patterns reflect the composite space–time variability of the phenomenon, whereas the number of realizations assumed is directly linked to the level of the agents' awareness about their incomplete knowledge of the phenomenon. It is noteworthy that the consciousness feature of CoP and the intentionality feature of TP (Section 3.5.3) are intimately connected. We have already seen that the consideration of multiple realizations (worlds) across space–time by the agent's consciousness in the CoP context is viewed as an intentional action. Many investigators believe that the most important conscious mental states are intentional states, and vice versa. It has been tirelessly pointed out that a conscious agent is an intentional human being, since one is goal-oriented and has purpose and aim in what one does in life. In this respect, the quantification of the CoP consciousness structure (in terms of some kind of mathematical operators) must respect the intentionality TP structure, and vice versa.

3.5.2 Concerning the CP

The knowledge classification introduced by CP – core and specificatory knowledge sources – is supported by the established methodology of physical sciences and the findings of life sciences. The description of a physical system generally demarcates between its *nomic* and *factual* features (Churchman and Ratoosh 1959; Eddington 1967; Feynman 1998). The former features include physical laws governing the system (expressing its universal and persistent aspects), and the latter features incorporate boundary/initial and relevant databases (representing the system's case-specific and contingent aspects). This distinction has a noticeable Aristotelian flavor. Aristotle introduced logic as a three-phase process (Chapter 5): Phase 1 considers core premises ("All men are mortal"); Phase 2 involves case-specific premises ("Socrates is a man"); and Phase 3 states the conclusion derived from the synthesis of the previous two phases ("Therefore, Socrates is mortal").

According to the findings of life sciences, learning and inference in the brain rest on an interplay between core (a priori) and site-specific (sensory data) sources. Irrespective of the precise mechanisms employed by the brain, the relative weight afforded by the two knowledge sources is a generic and important issue (Friston 2002). Evolutionary psychology views human behavior as a product of two complementary parts: the agent's human nature (core part) and the agent's unique individual experiences and environment (specificatory part). Neuroscience assigns to hemispheric complementarity several intriguing features. As we saw in previous sections, one of these features is that the two hemispheres show different response selection biases. Although agents feel "free" to make decisions according to their own preferences in daily life, cognitive control over such situations depends on two types of brain operations (Aoyagi et al. 2005): those guiding behavior by internal representations, and those carrying out exploratory processing of novel cognitive situations. The left hemisphere is the repository of compressed knowledge that enables the agent to deal efficiently with familiar situations, whereas the right hemisphere is the novelty hemisphere that explorers new data about the specific situation (Goldberg 2005). Experimental gamma-frequency EEG studies showed that during the initial exposure to a novel task, the right brain hemisphere is mostly active. However, when a familiar task is considered, it is the left hemisphere that is mostly active (Kamiya et al. 2002). Other studies that reach the same conclusion are found in the literature (Goldberg and Costa 1981; Milner and Petrides 1984; Floel et al. 2005).

In Section 3.3, we saw that the development of a mental model of the real-world passes through different stages: The agent starts with an initial model based on phylogenetic memory, a kind of core knowledge the agent is born with. At subsequent stages, the current model is updated in light of the new data that become available. In relation to this process, Noam Chomsky suggested that experience is simply not enough to yield complex knowledge without presupposing a biologically endowed (core) knowledge acquisition device in the brain. CP takes into account the suggestion that humans are born with innate dispositions to know (formalized in terms of core knowledge processed by the left hemisphere), with specific potentials for further experience (formalized by the specificatory knowledge assimilated in the right hemisphere). The reader may find it interesting that referring to Plato's *Meno*, Noam Chomsky once remarked that (Chomsky 1986), "Plato's problem, then, is to explain how we know so much, given that the evidence available to us is so sparse." Read Montague adopted a similar viewpoint (Montague 2006: 92): "No system can start from scratch. No learning systems start without some assumptions about the problems they will face and how they might learn about them. A system with absolutely no assumptions could never learn. And biological systems are the best examples of 'non-scratch' learning systems, since they all start with a deep biological lineage encoded in their DNA." Epibraimatics's suggestion is to establish a living experience framework for integrating core and specificatory, multidisciplinary and multithematic knowledge sources (scientific, cultural, and social) for IPS purposes. This requires that one reads the data numbers as one reads a face, with a great deal of attention, knowledge, and experience. Accordingly, the agent's living experience framework possesses explanatory and predictive context, in addition to descriptive.

3.5.3 Concerning the TP

This postulate can be justified on the basis of philosophical and scientific arguments. TP includes elements of Aristotle's final cause and Hegel's dialectical reasoning (Section 2.2). Two prime TP features are reasoning and information. TP is consistent with modern theories of mind concerning the *prescriptive* manner in which mental reasoning handles knowledge – acquiring, processing, relating, and responding to it (Touretzky et al. 1995). Humans act on intentions and this includes problem-solving. Intentionality precedes observation. Peter Medawar (1969: 29) has suggested that, "Any adequate account of scientific method must include a theory of incentive or special motive." Cognition research has discovered that prior to each act of observation leading to perception, there emerges within the brain a pattern of neural activity that establishes the goal of the act (Freeman 2000). This neural activity, which underlies intentional action, generates neuron firings that engage the body into a goal-directed behavior (most of the agent's intentional behaviors unfold habitually), and also sends neural messages to the primary sensory areas of the body that prepare them for the consequences of the intended actions. The idea of an acting agent (one who intends) rather requires a conscious mind with its contents. The reader may recall that intentionality distinguishes mental from physical states, since the latter lack intentionality. Correspondingly, the intentionality concept underlying the TP has a clear prescriptive character expressed in teleology of reason terms (Roskos-Ewoldsen and Monahan 2002). To borrow a metaphor from Brad Thompson (2003), to understand a car journey, one looks at the purpose of traveling rather than taking the engine apart.

Intentionality may be also linked to the other main feature of the TP: *Information*. Indeed, Thompson maintains that intentionality refers to the way in which minds handle information "about" an entity and has the effect of controlling behavior. Moreover, other studies maintain that information processing is a key cognitive link between agent's perception and behavior (action); D'Esposito et al. (2000), and Fuster et al. (2000). Many behavioral aspects could be understood if one assumes that an agent seeks to *maximize* the rate of information gain (Pirolli and Card 1999), which is also the focus of the TP. As the analysis of the CP revealed, experimental evidence suggests that the left hemisphere is the repository of compressed data that enables the agent to consider and process pre-existing core knowledge and familiar situations. Accordingly, TP offers a representation of the way this processing could be done, i.e., an initial problem–solution is obtained at the TP stage in terms of teleology of reason criteria (e.g., seeking information maximization) subject to the pre-existing core knowledge. Functional neuroimaging studies have indicated hippocampal sensitivity to the expected information of events (prior to their occurrence) that can play a fundamental role in perceptual synthesis (Strange et al. 2005). Other investigations offer evidence that human information seeking has evolutionary precedents. For Daniel Dennet (1996), "Evolution embodies information in every part of every organism." Dennett goes one step further when he suggests a distributed information sucking system, each component of which is constantly fishing for information in the environment. They are all intentional subsystems, which get organized in a higher-level intentional system, with an "increasing power to produce future." Lila Gatlin (1972: 1) argues that, "life may be defined operationally as an information processing system – a structural hierarchy of functional units – that has acquired through evolution the ability to store and process the information necessary for its own accurate reproduction." In sum, humans seek, gather, share, and consume information in order to adapt (Gratton et al. 1992). Along this line of argumentation, maximizing the information provided by the problem–solution in terms of TP implies maximizing its fitness. In linguistics, according to H. Paul Grice's theory of efficient communication, people generally follow certain rules, also known as Gricean maxims (Grice 1975). One of these rules is the so-called "Maxim of Quantity": when making a statement one should supply the maximum relevant information. It is noteworthy that the most enthusiastic supporters of the human information seeking theory among psychologists refer to humans as *informavores*, thus suggesting that humans consume information in an analogous way they consume food (Miller 1983; Pinker 1997). In a somehow different context, cognitive scientists use the term "informavore" to refer to the agent's ability to manipulate representations of the outside world inside the brain and transmit information to other agents through language. In any case, these are key abilities that distinguish human agents from other species.

3.5.4 Concerning the AP

The motivation behind the AP includes cognition theories focusing on the adaptive abilities of the human mind in light of updated knowledge as a result of evolutionary mechanisms (Johnson et al. 2002). The reader may recall the fundamental idea that evolution depends on one's success to adapt to changes in one's environment, often under conditions of *uncertainty*. From an evolutionary perspective, there is a close functional link between the new knowledge creating the specific adaptation situation and the brain's mechanisms that evolved in order to handle the situation. In fact, as we saw in our analysis of the CP, experimental evidence shows that the right hemisphere is the novelty hemisphere that processes new data concerning the specific situation. Accordingly, the AP offers a representation of the way this processing could be done, i.e., by adapting the problem–solution obtained at the TP stage in order to account for specificatory knowledge. In this setting, the twofold goal of AP's involvement in the IPS process is to: (i) be consistent with cognitive and evolutionary findings above; and (ii) account for the agent's understanding of the specific problem. Item (ii) includes the underlying physics, social characteristics, and logical constraints (in the case, e.g., that the core knowledge considered at the TP stage diverges from the site-specific knowledge collected at the AP stage, what relative weights should adaptation give to the two different knowledge sources?) In Chapters 5 and 6, we shall see that an adequate mathematical expression of this twofold adaptation involves stochastic reasoning, probabilistic conditionals, internal consistency criteria, and knowledge of the physical mechanisms associated with the environment under consideration.

How a problem–solution fits in with what is already known is a matter of considerable epistemic interest. Generally speaking, scientific inquiry deals with questions of validity, truth, knowledge reliability, and method. Gerd Gigerenzer (2007: 19) entertained the idea that "the mind can be seen as an adaptive toolbox with genetically, culturally, and individually created and transmitted rules of thumb." While Gigerenzer focuses on psychological rules that bet on simplicity, Epibraimatics' view is that the "toolbox" should include principles (logical, epistemic, and psychological) that can take advantage of mental functions linked to the evolved brain mechanisms.

3.5.5 Parmenides' Gate and Morrison's Doors

We conclude Section 3.5 with a metaphor. The readers who happen to be "die-hard" funs of the legendary rock group "The Doors" may recall that Jim Morrison, the group's lead singer, was fond of saying that,

> There are things known and things unknown and in between are *The Doors*.

One can draw an intriguing parallel between the metaphorical meaning of "The Doors," as expressed in Jim Morrison's quote above and the meaning of the "Gate" in Parmenides' Poem discussed in our introduction to Chapter 1. In both cases, the role of the "Gate" and the "Doors" is to offer a critical link between the unknown and the known, between the world of ignorance and the world of knowledge.

Mutatis mutandis, the goal of scientific inquiry, in general, and problem–solution, in particular, is to slightly crack the door (or the gate, whatever the case might be) that connects the unknown with the known. Scientists often view and interpret the world around them, both natural and cultural, using perceptual and cognitive means of their own construction. The four IPS postulates proposed above are concerned with the processes (perceptual, cognitive, imaginative, and linguistic) by which understanding is achieved and communicated as well as about when and how to use various methods to develop knowledge and solve problems. The IPS postulates suggest that, in order to solve a real-world problem some sort of a structure must be assigned to it; an adequate problem space must be created on the basis of core knowledge and specificatory data from various sources; and the solution will emerge by means of the dialectic between the problem space and the agent. The dialectic may guide the agent on how to organize and transform the problem space, revise the solution plan in light of new knowledge, discard elements that lead to dead ends and, when necessary, break out of the shackles of mainstream thinking and seek a fresh perspective. At the conceptual level, some readers may find some partial links between the IPS framework suggested by the four postulates and the well-known Piaget's learning process (model-assimilation-adaptation) as well as the Merleau-–Ponty's process of hypothesis testing seeking to achieve maximum grip through an intentional act (Merleau-Ponty 1964). The matter is revisited in subsequent sections. Assessing the consequences of these postulates in real-world IPS situations can also advance understanding of the brain's architecture itself. Chapter 7 will attempt a *quantification* of the postulates and consider their implementation in developing a rigorous IPS theory. Epibraimatics' perspective is that just as the study of physical phenomena (movement of planets, gravity etc.) gave rise to new mathematics (e.g., differential calculus), so the study of mental functions and associated brain activities could be the source of innovation of more useful mathematics.

3.6 Knowledge Bases

For Epibraimatics purposes, the term *knowledge base* (KB) characterizes a systematically organized collection of data sources concerning an in situ situation. Speaking metaphorically, a prime goal is to transmute the various individual KBs into a single integrated KB that provides the big picture in a meaningful and effective manner – a process that is analogous to looking at a photo and seeing a single image rather than a multiplicity of individual dots. We refer to KBs in various parts of the book, in which case it should be obvious that a KB may be constructed using a rich variety of methods. Physicists and chemists, e.g., gain knowledge usually through an inductive method, whereas historians and social scientists often use a teleologic method; also, in medical science the physicians consider clinical judgment as valuable tacit knowledge. This has the remarkable consequence that the solution of a problem with multidisciplinary elements should make it possible to draw together KBs obtained using distinct (and sometimes even contradictory) methods into a single organized system. Let us have a closer look at the KB notion in the light of the basic IPS postulates introduced in the previous section.

3.6.1 Knowledge Classifications

The readers are reminded that one could assign two senses to the notion of knowledge classification: (a) The cognitive sense, which refers to the assessment of the cognitive value and epistemic validity (logical or physical) of the different knowledge sources (Section 1.1.3). (b) The social anthropology sense, which is concerned with the socio-historical framework that shapes many forms of knowledge (e.g.,Section 1.4). Even if a scientific study focuses predominantly on Item (a) (which is also the focus of the present section), it should be, nevertheless, aware of Item (b).

As was suggested in the context of the CP, a well-justified classification of knowledge is between two major categories: *general* (or core) KB, denoted by *G*, and *specificatory* (or site-specific) KB, denoted by *S*. In this sense, the present section may be seen as a continuation of Section 3.5.2. As one assesses the state of the art of KB determination across the broad spectrum of human endeavors, this is an epistemically sound classification as well as a fruitful one for purposes of IPS viewed as a knowledge synthesis affair. Although this is not the only KB classification possible, certain sound arguments attesting in its favor are examined next.

3.6.1.1 The G-KB

The *G*-KB considers core knowledge of wide applicability, usually gathered during many years of human effort and evolution. Such knowledge may include scientific theories, natural laws, phenomenological models, cultural relations, and long-established worldviews. In his usual eloquent style, Lewis Lapham (2008a: 12) writes about the human journey and the past record of Man stored in the mind:

> Within the first six years of life, the human mind replicates the dream of its five-thousand-year journey from the sand castle cities of Mesopotamia. The figures in the dream have left the signs of their passing in what we know as the historical record, navigational lights flashing across the gulf of time on scraps of papyrus and scratchings in stone, on ships' logs and bronze coins, as epic poems and totem poles and painted ceilings, in confessions voluntary and coerced, in five-act plays and three-part songs.

The core knowledge also includes what was earlier described as phylogenetic memory, which is an important component of the stored record in the brain that determines whether or not a human agent survives long enough to reproduce.

Natural laws (Table 1.1) – especially in a stochastic form that accounts for the epistemic fact that some or all of the attributes, parameters, and auxiliary conditions of a natural law are often incompletely known – constitute a prime component of the *G*-KB. As far as the sciences are concerned (at least the hard ones, like physics and chemistry), the most advanced predictive methods are those based on laws governing the natural system of interest and expressed in a mathematical form. In this sense, every essential attribute is lawfully related to other essential attributes. As noted earlier, many physical laws reflect nomic features of the system (i.e., universal and persistent features), and as such, they express structural system mechanisms that go beyond mere phenomenological relations. Other laws (biological, ecological, etc.) hold for a specific system (subspecies, domain, race, and population). Of considerable usefulness, although usually of a lower level of fundamentality than natural laws, are the computer models (routinely implemented in a wide variety of applications ranging from weather prediction to economic forecasting). The conceptual structure of the *G*-KB properly recognizes the power of natural laws and the versatility of computational models, but is also aware of the potentially serious effects of uncertainty and space–time heterogeneity. The effort to achieve a quantitatively meaningful blending of the two (the structure of the laws and models, on the one hand, and the uncertainty and heterogeneity of the in situ conditions, on the other) relies on stochastic reasoning tools (Chapters 5 and 6). It is noteworthy that the improvement of computer models may reach a limit since it relies heavily on increasing computing speed. As Lev Levitin and Tommaso Toffoli have shown, computers have an unbreakable speed limit. "No system can overcome that limit. It doesn't depend on the physical nature of the system or how it's implemented, what algorithm you use for computation . . . any choice of hardware and software," Levitin said. "This bound poses an absolute law of nature, just like the speed of light" (Schenkman 2009).

For many practical purposes, the *G*-KB often includes dependence functions of different theoretical origins (covariance, structure, variogram, sysketogram, and contingogram functions; Chapters 4–6) that are known to adequately describe the core spatiotemporal features of a wide range of natural systems under conditions of uncertainty. Spatiotemporal dependence functions are derived from scientific theories, physical laws, empirical relationships, or interdisciplinary associations that are well established and of general validity. A physical law of an attribute distributed across space–time could lead to the corresponding dependence equation, which, in principle, can be solved to yield a valid theoretical space–time dependence model. In short, the G-KB is the fund of knowledge available to all competent thinkers belonging to a certain culture and possessing a certain expertise (social, scientific, mathematical etc.). Concluding this section, one may notice with amazement that a G-KB that is based on wisdom of the past ("the best that has been said and thought in the world," in Matthew Arnold's words) is irretrievably lost in the postmodern world.

3.6.1.2 The S-KB

The *S*-KB has a different structure than the *G*-KB. The *S*-KB considers different sources of evidence that are tied to the particular in situ situation and may be not of general validity. The sources include: *Hard* (exact) measurements with a satisfactory level of accuracy and expressed as numerical attribute values across space–time. They may refer, e.g., to temperature (96^oF), building height (53.25 m), vote count (119 votes), or mortality rate (2 deaths due to the H1N1 virus per 10,000 inhabitants). *Soft* (inexact) data involve a significant amount of uncertainty. These data appear in many forms, such as secondary evidence, interval attribute values, and probability distributions[16] that approximate local or global data attribute in a space–time domain.

The *S*-KB could include datasets about attributes with very different substantive features (e.g., their units may be not mutually convertible). Nevertheless,

[16] Gaussian, triangular, uniform, or even custom-defined probability distributions.

potentially valuable empirical evidence is obtained by identifying those attribute properties that can be expressed quantitatively. Data from different fields of expertise are shown in Fig. 3.1. Fig. 3.1a displays social strata data associated with neural tube defects (Heshun county, China) that have been studied by Jinfeng Wang and co-workers (Wang et al. 2010). Unlike physical KBs, social KBs are linked to thinking participants who can interact with elements of the problem–solution. Useful KBs are increasingly available in terms of images produced by satellites orbiting the Earth. Fig. 3.1b is an image of the devastating fires in central and southern Greece (August 2007). In another interesting study, Williams and Stow (2007) developed KBs consisting of forest metrics (at different spatial scales)

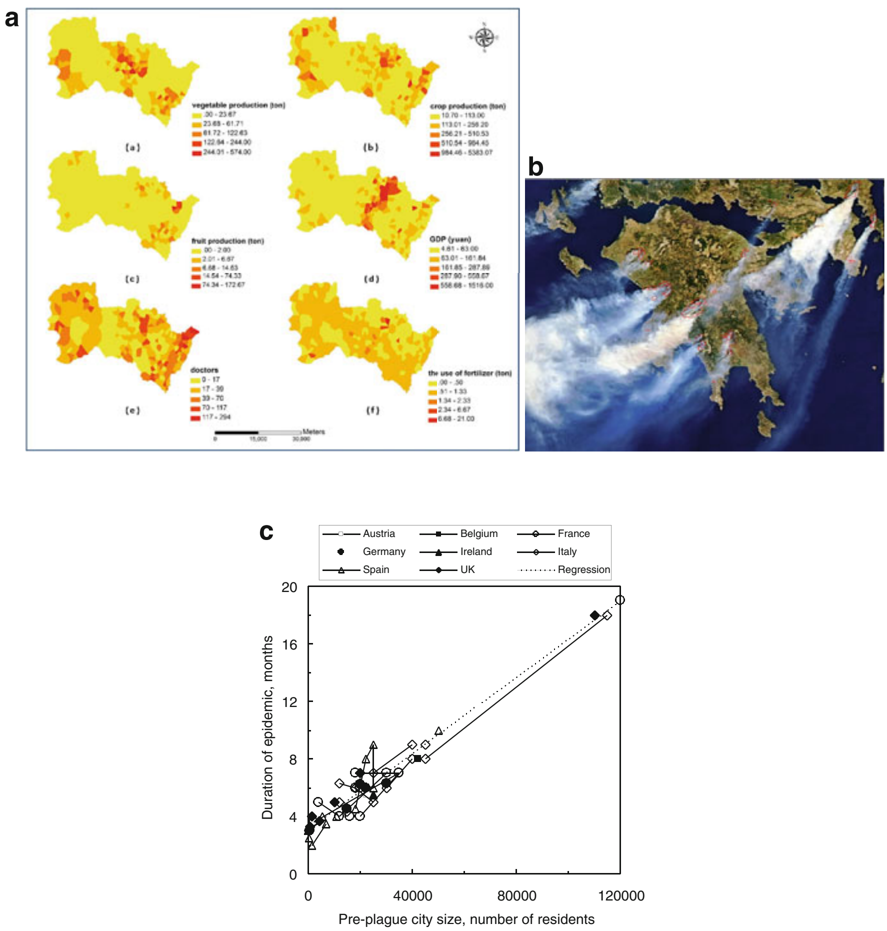

Fig. 3.1 (**a**) Social strata associated with the distribution of neural tube defect cases (Heshun county, China). (**b**) A satellite image of the fires in central and southern Greece during August 2007. (**c**) A scaling law of Black Death duration vs. preplague city size

from multi-spectral IKONOS satellite imagery, and subsequently used them to determine forest characteristics preferred by monarchs when colonizing their over-wintering sites. Lastly, in Fig. 3.1c, we see a historical KB in the form of a scaling law, $\Delta_{\boldsymbol{s}} = 3.031 + 0.132 P_{\boldsymbol{s},0}$, where $\Delta_{\boldsymbol{s}}$ denotes the local duration of the fourteenth century Black Death epidemic in Europe (in months) and $P_{\boldsymbol{s},0}$ denotes the urban population (in thousands of residents) immediately before the start of Black Death at each geographical location $\boldsymbol{s}$ (Olea and Christakos 2005). This scaling law is an intriguing knowledge expression in which historical data are expressed in a rigorous mathematical form. These and several other KBs (Fig. 1.2) were examined with the underlying diagnosis of the social, political, and economic environment of the Middle Ages as one in which for a large part of the population it was indecent to think. In many cases, an *S*-dataset is most valuable to IPS when blended with other *S*-datasets. For example, the importance of satellite and aircraft datasets improves considerably when combined with ground data. In other in situ situations, the *S* reduces to a limited dataset, which may be due to the inability to obtain the necessary data (equipment limitations, financial costs, etc.), or due to the inability to use the existing data. In health sciences, e.g., a limited dataset could be a limited set of identifiable information in which most of the identifiers for the individual, the individual's relatives, employers, and household members have been removed. There are also cases in which the limited structure of the dataset is due to the fact that the boundaries between the known and the unknown, and between the knowable and the unknowable, are not explicit but rather convoluted.

In a certain respect, *S* may be older than *G*. The knowledge of ancients was initially practical (how to build a shelter, which fruits are poisonous, or how to light a fire). *Mutandis mutatis*, this knowledge of ancients can be seen as a primitive form of *S*-KB. With time, ancients developed a curiosity about things that led to theoretical knowledge (how far away the stars are, what causes lightning, what is the meaning of life, etc.); this theoretical knowledge may be seen as a primary form of *G*-KB. If history is any guide, asking theoretical questions of this kind also has great practical value, since it can initiate change in people's lives in more than one ways (Arntz et al. 2006).

3.6.1.3 Justifications of Basic Knowledge Classification

Looking at the CP from different angles may not merely provide multiple justifications of the particular postulate, but could potentially enlighten certain aspects of the brain–mind affair from an IPS perspective. Having said that, the basic classification between *G*-KB and *S*-KB suggested by the CP finds additional support and fruitful interpretation in various modern fields of inquiry, as follows. In *neurosciences*, one of the three major properties of cortical memory in humans is the "invariant" representation, which refers to the fact that the brain preserves the core knowledge of the world (*G*-KB), independent of the specific details (*S*-KB). As Jeff Hawkins points out, memories are stored in a form that captures the essence of relationships (Hawkins 2004). Then, humans understand the world by finding invariant structures on the basis of stored knowledge. However, this invariant structure alone is not sufficient to use as a basis for making predictions. In order to make predictions, the brain blends knowledge of the invariant structure (vis-à-vis, *G*-KB) with specific details of the situation (*S*-KB). The distinction between *G*-KB and *S*-KB finds considerable support in *sociobiological* studies, which have demonstrated that at a very fundamental level, the goal of human behavior is to distinguish between sensory data (*S*) and stored knowledge (*G*) of the structure of the world, and then to use them to generate motor responses that are adaptive, i.e., they seek high inclusive fitness for an organism (Wilson 1975).

Furthermore, the knowledge categorization above is linked to an interesting metaphor in the field of modern *evolutionary epistemology*. Both Darwinian evolutionary theory and traditional epistemology are accounts of the growth of knowledge. Evolution is itself a knowledge process in which information regarding the environment is incorporated in surviving organisms through the adaptation process (Radnitzky and Bartley 1993). Two kinds of knowledge are assumed in an evolutionary epistemology context: *endosomatic* knowledge, as incarnated in organisms through years of evolution (corresponding to *G*-KB), and *exosomatic* knowledge, as encoded in new experiences with the environment (*S*-KB). In the former case, there is an increasing fit or adaptation between the organism and the environment when its stored templates model stable features of the environment, whereas in the latter case there is an increasing fit between theory and fact. In the evolutionary epistemology context, the *G*-KB is combined with the *S*-KB in an appropriate manner, which means that the two kinds of knowledge are adaptationally continuous.

3.6.1.4 Other Kinds of Knowledge Classification

The blending of different kinds of KB invoked by a critical reasoning process aims at the conscious solution of real-world problems. The validity of a KB element cannot be assessed in the radical postmodern sense of "everyman's guess is equally admissible," but on the basis of substantive evidence, systemic interconnectedness, and sound theorizing. Questions about which KBs are the most reliable and the most important in the IPS context immediately arise. To address these questions, an agent needs to ask for a classification of sorts of knowing, a ranking of these sorts by reference to some reliability and value standards, and a meaningful uncertainty characterization (say, conceptual vs. technical, or epistemic vs. physical).

In view of these and similar considerations, Fig. 3.2 reviews different kinds of KBs classification in addition to the classification considered by the CP. The KBs can be classified (*inter alia*) into knowledge referring to the microlevel vs. the macrolevel of the in situ phenomenon; according to the coordinate systems selected as appropriate for the situation; by means of scale and spatial dimensionality; in terms of the major discipline of origin (e.g., physical vs. health), or by taking into account the different variables and multiple instruments involved. Consequently,

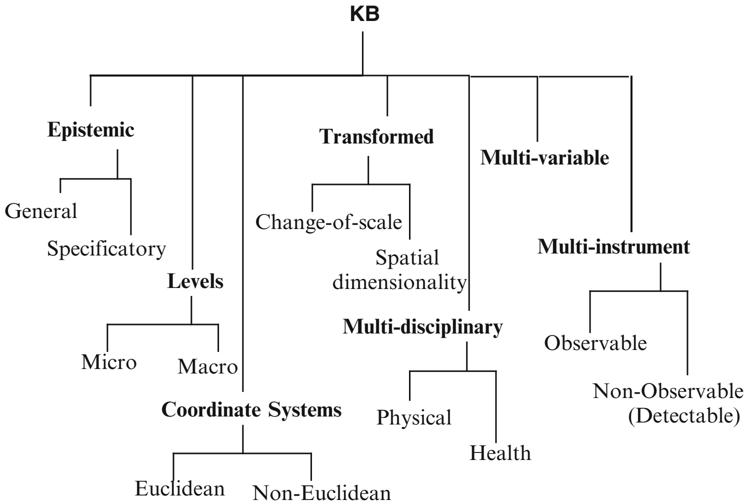

Fig. 3.2 An outline of possible KBs classifications

the choice of a KB classification would depend on a number of IPS factors: Physical properties of the problem, agent's criteria seeking to improve understanding, problem–solution objectives, or broader context to which the solutions belong (e.g., decision-making). It is also possible that the solution of an in situ problem requires the consideration of several of these KB classifications simultaneously. The book invites the readers to reflect and speculate about these important issues in the context of a broader IPS conception.

3.6.2 The Sant'Alvise Nuns in Old Venice

Making a scientific observation or measurement usually is not a trivial matter (Section 1.7). Generally, as a conscious creation of the human mind, a KB may involve several entities of significance to human life (attributes, objects, processes, and systems). Section 1.1 brought to our attention salient issues of knowledge acquisition and processing (such as measurement vs. observation, and measurement processes vs. measurement process). In a similar spirit, the following distinctions are worth considering: (a) *Observable* entities vs. *inferred* (or *detectable*) entities. (b) *Observer-independent* entities vs. *observer-dependent* entities. (c) *Qualia* of an entity vs. *observable facts* about it. (d) *Subject* (observer) vs. *object* (observed). (e) *Observation* vs. *mirror neuron activity*. A few examples may illustrate these distinctions. Let us start with a little dose of culture. One of the best-known sixteenth century Venetian nunneries was that of *Sant'Alvise* (Laven 2003). The imposing structure of its church was connected directly with the convent that was home to over a 100 nuns. They would come to the choir to perform their daily duties out of the sight of the public. One could not observe the nuns, but would draw inferences about how they looked like, their education level, their families, and social status, and the like. Entities such as flowers and mountains are certainly observable. However, there are other entities that – like the Saint' Alvice nuns – can only be inferred. Resorting once more to *licentia poetica*, generating data of inferred entities is often a process as dramatic as listening to the eerie sound of the disembodied voices of the Saint' Alvice nuns shielded from view by high walls in the old Venice convents. Just as the nuns, entities like electrons are not observable (in the ordinary sense) – they are only detectable by means of special equipment (particle detectors etc.). Such entities are thus inferred in the sense that the scientific structure they form part of explains what an agent experiences. By observing how light from galaxies has been bent, scientists can use the theory of relativity to infer the quantity and location of the matter that did the bending. On the other hand, entities like ether that are unobservable and also failed to satisfy the detectability (inference) requirement no longer make sense and are deemed useless. The second example involves a different perspective. While entities such as mountains exist independently of any observer, entities such as a banknote are no more than pieces of paper without the observer's mind to think of them in a financial context (e.g., a banknote that goes out of circulation becomes a piece of paper). In this sense, it is the conscious mind of the observer that assigns a function or purpose to an entity, without which the entity has no meaning in the knowledge context. Humans have, indeed, the ability to differentiate observable material objects from unobservable minds.

Qualia constitute a subtle issue that briefly concerned us in Section 3.2. Although they provide critical knowledge, the quale of an entity cannot be determined by the physical facts about it, i.e., qualia are separate from observable data (Sternberg 2007). In 1900, Husserl and Freud attempted to unify subject (observer) and object (observed) in philosophy and psychology, respectively; see "Logical investigations" (Husserl) and "The interpretation of dreams" (Freud). Five years later (1905), Einstein published "The special theory of relativity" in which he introduced essentially the same idea in physics. Observability and observer-independency are linked to scientific *realism* (according to which the physical world exists independent of human thought and perception), whereas unobservability and observer-dependency may be associated with scientific *idealism* (where the physical world is in some way dependent on the conscious activity of agents). This distinction, in its various expressions, arises again-and-again in almost all matters of scientific inquiry. Also, observer-dependency is related to Husserls's idea of intentionality that was introduced in Section 3.2.3. Husserl, a student of Brentano, extended his idea of intentionality beyond mere "aboutness." Husserl realized that all perception is intentional. The *dialogue* between observer and observed involves the conscious interaction of one's mental functions with Nature. If agents do not fire their attention at something, they do not see it; or rather they see it "mechanically," hardly noticing it (Wilson 2006: 15). If Aglaia, e.g., looks at her watch absentmindedly, she does not notice the time and has to look again, this time "intending" it.

Experiments in neurosciences have revealed the existence of *mirror neurons* in an agent's brain, i.e., neurons that mirror the activity of others. Mirror neurons may have contributed significantly to important evolutionary facts: Agents can learn by observing a phenomenon rather than having to figure it out step-by-step. An agent experiences an event rather than merely observing it as a nonparticipating outsider. When a parent smiles, e.g., a newborn child reacts by smiling back, which raises a number of critical neuroscientific questions (how does the newborn child know what muscles to move to produce the smile, etc.; Byrne and Levitin 2007: 46). Lastly, when one watches a musical performance, one is not just observing a group of people playing some instruments. In a neurological kind of way, one is also experiencing what one observes.

3.6.3 Papists and Experimentalists

As was pointed out before, many quantitative methods place too much emphasis on "how" (preoccupied with operations and procedures to process information) and very little on "why" (understanding the meanings of what we know rather than merely accumulate information). For example, researchers should be concerned not only *how* the data were obtained, but also *why* they should be believed to be reliable. The lack of critical thinking in data generation and interpretation together with the lack of collaboration between theorists and experimentalists can yield questionable results, in which case their use may imply a considerable amount of risk. Just as in the early sixteenth century, the chief trouble of the papists was to avoid the scrutiny of their practices[17] by the new ideas of the Lutheran movement, a prime concern of many of today's experimentalists is how to avoid the critical evaluation of their practices by their theorist colleagues. There is a plethora of examples in which scientists refuse to share their data with their colleagues, whereas at the same time they outright reject the viewpoints of their colleagues. The incident of Climategate (Section 1.6.2.2) is instructive in this respect. Another interesting example is the case of ancient DNA studies. Several reports have questioned the reliability claims concerning the recovery of ancient DNA (Bryson 2003: 465). Techniques used to study ancient DNA contain inherent problems, particularly with regard to the generation of authentic and useful data. Recent studies emphasize that efforts to reduce contamination and artefactual results by adopting authentication criteria that are not foolproof have, in practice, replaced the use of thought and prudence when designing and executing ancient DNA studies (Gilbert et al. 2005). Remarkably, this sort of unreliable experimental data lacking sound theoretical support has played an authoritative role in the critical debate

[17] Like the sale of "indulgences", a sort of certified checks drawn by the Pope on the treasury of merit accumulated by the saints. Buying one enabled the holder to finesses penance and shorten one's time in Purgatory (Barzun 2000).

concerning the etiology of Black Death, one of history's deadliest epidemics (Christakos et al. 2005, 2007).

A KB is basically *contextual*: consideration of the KB environment and validity conditions is needed in order to transfer data around and establish an appropriate interpretation. Metaphorically speaking, a sort of a "conversation" ensues during which understanding can be developed. Facts and data do not speak for themselves, they always need interpreting. In the nineteenth century, John Stuart Mill remarked: "Very few facts are able to tell their own story, without comments to bring out their meaning" (Mill 1985: Chapter 2). Similar was the view of Charles Darwin, who in 1861 observed that (Darwin and Seward 1903: 176),

> About thirty years ago there was much talk that geologists ought only to observe and not theorize; and I well remember someone saying that at this rate a man might as well go into a gravel-pit and count the pebbles and describe the situation. How odd it is that anyone should not see that all observation must be for or against some view if it is to be of any service.

The matter was discussed in due detail in previous sections. One is constantly reminded that whether one is dealing with a simple or a complex problem, data make sense only within a given paradigm or worldview – this is called *data relativity*. There is a definite mental process (sometimes naïve and some other times quite sophisticated) that connects the observed and the observer, and leads from data to inferences and conclusions. Historical records have repeatedly shown that data and facts are often twisted to suit specific purposes or desired interpretations of the clerkdom of the time. As noted earlier, in modern times one's refusal to obey the orders of the power holders and their interpretation of the facts can lead to the undeserved termination of one's career (scientific, political, or social). During the old times, things sometimes could be more serious. A testimonial to the clerkdom's brutality is the tragic story of Hypatia of Alexandria, already mentioned in Section 1.3.2. She was a Neoplatonist philosopher and the first notable woman in mathematics. Hypatia lived during the late fourth–early fifth century in the city of Alexandria of Roman Egypt, and she was murdered by a Christian mob that attacked her, stripped her, and killed her with pieces of broken pottery. Later, the mob dragged her dead body through the streets of Alexandria. The reason for her brutal murder was her conscientious decision not to accept the "desired" interpretation of the facts (political and historical) that served the spiritual and political plans of Cyril, the Patriarch of Alexandria (Deakin 1994; Dzielska 1995).

3.6.4 KB Consistency

The issue of consistency between the different sources of evidence available in a real-world study deserves special attention. Logically, an inconsistency arises when some entities (e.g., theses, concepts, datasets), while individually plausible, are collectively incompatible. In physical sciences, it was early discovered that different experimental datasets could generate inconsistent estimates of physical constants (Birge 1932). In health sciences (Mathers et al. 2002: 611), given the different nature of disease attributes (incidence, prevalence, case fatality, duration, and mortality) and differences in data acquisition techniques, it is inevitable that some observations are internally inconsistent (e.g., when more incident cases than mortality are missed, the observed incidence will be too small for the observed mortality). Similar is the case of risk assessment (Brand and Small 1995).

While statistical studies have considered the derivation of formal methods for combining multisourced evidence (Ades 2003; Spiegelhalter et al. 2003), they completely neglected the significance of consistency between these different sources (Ades 2004). This may be due to the fact that the resolution of the consistency problem is not a statistical issue but a matter of scientific substance. It is then upon scientific expertise to decide whether a physical model of the *G*-KB is conceptually inadequate,[18] the observational data of the *S*-KB are so uncertain as to be useless, or the experimental arrangements do not generate accurate estimates of model parameters. In IPS, the inconsistency issue may enter the agent's thinking mode in two main ways: (a) There is clear evidence of inconsistency between certain elements of the *G*-KB and the *S*-KB and a rigorous method needs to be developed to resolve the issue; or (b) although there is no clear evidence of inconsistency between the *G*-KB and *S*-KB, the agent is not certain that consistency can be taken for granted. Despite the significance of the matter, there is not a generally established quantitative approach to deal with multisourced KBs consistency. In hard sciences (such as physics and chemistry), an agent traditionally recognizes the epistemic priority of the *nomological* elements of the *G*-KB over the factological ones of the *S*-KB. On the other hand, many statistical models give priority to *factological* elements such as site-specific datasets. In these cases, an inconsistency between the core KB and the datasets available is explained by the possibility of the core knowledge being less reliable than the datasets. Also, the *S*-KB may be given priority over the *G*-KB in the case of an evolving in situ system in which the *G*-KB is associated with the past state of the system, whereas the *S*-KB better represents its present state.

The matter becomes more complicated when a multidisciplinary problem–solution is sought (the level of fundamentality of the corresponding laws and models varies, there are various data sources that have a bearing on model parameter estimation, etc.), and the union operator that synthesizes the different KBs to produce the integrated KB, say $K = G \cup S$, must maintain a certain level of consistency between the elements of the *G*-KB and *S*-KB. An interesting situation involving many different KBs was the multidisciplinary study of the world's greatest recorded epidemic, namely the Black Death epidemic in fourteenth century Europe (for a detailed discussion see Christakos et al. 2005; also Chapter 6). The consistency of these KBs was of great significance and, accordingly, it was handled in a rigorous and systematic manner. A typical example is the KBs about Florence

[18] That is, it offers an incomplete representation of the system under consideration; see conceptual uncertainty in Section 4.3.2.4.

and Bologna (Italy), which included the following elements: (a) in both cities the area inside the city walls was approximately the same (420 ha); (b) there were no dwellings adjacent to the city walls, and the duration of epidemic in both cities was 8 months; (c) the preplague population of Bologna was 40,000 residents, and the duration and population were linked through an empirical scaling law; and (d) previous studies have claimed that the preplague population of Florence was about twice that of Bologna. As it was shown, the KB elements (a)–(c) contradicted element *d,* and in order to restore consistency the KB element (d) had to be revised accordingly. In some cases, the so-called "weakest link principle" may be useful (Rescher 2009). In the presence of inconsistency, KB elements expressing facts of lesser generality should be abandoned in favor of elements of greater lawful generality. Consider, e.g., the inconsistent KB that includes the possibilities $\chi_i \vee \chi_j$, $\neg\chi_i$, and $\neg\chi_j$. Pure logic can merely detect the inconsistency in the KB and then require that consistency is restored, but it cannot indicate how exactly this can be done. The *logic-external* "weakest link principle" is useful in this respect by suggesting the elimination of the possibility that constitutes the weakest link in the KB consistency chain. Other principles include the "simplicity principle" (e.g., see Occam's razor in Section 8.2.3): In the presence of inconsistency, other things being equal, the KB elements of higher simplicity[19] should be given priority over more complex ones. And the "uniformity principle": In the presence of inconsistency, the KB elements that exhibit a closer analogy (pattern) with otherwise validated cases should be preferred over elements lacking such validation.

The crux of the matter is that the consistency of the different *G*-KB and *S*-KB elements (involved in the quantitative representation of the TP and AP, respectively) is crucial. Quantitative IPS representations need to develop (*inter alia*) rigorous techniques that use logic-based or logic-external principles for combining KBs (structured in complex ways) in a manner that breaks the chain of inconsistency and, at the same time, retains as much information conveyed by the conflicting KBs as the logical reasoning and the epistemic conditions of the real in situ problem allow (Section 7.3.4).

3.7 Problem–Solutions Suspended in Language

So, is language an issue? To some extent, a language has an effect on one's perceptions of reality, although the word is not the thing, i.e., the words by which one defines reality are not the same as the things they designate. Scientists need a language in which to express and communicate their thoughts, but this is not enough, it is but an opening onto the reality of the external world – language must be capable to represent this reality etc. The matter deserves more attention, which is why I

[19] Simplicity here is meant in the epistemic rather than in the "simplicity of Nature" sense.

devote this section to identifying dynamics central to the substantive association between language and scientific inquiry.

3.7.1 George Steiner's Perspective

Many societies and cultures have been multilingual. For several centuries, the educated throughout Europe used Latin when in discourse with each other while being, simultaneously, practitioners of their own vulgate. This practice often had considerable epistemological consequences. For George Steiner (1998: 88–89), "Many of the perplexities which arise out of the epistemology of Descartes stem from the fact that Latin was the first language of his meditations, that translation into his native French proved recalcitrant also to himself."

Steiner's observation is valid in a general setting. Human agents view the world in different ways depending on their varying "models" of it (a model is constructed on the basis of one's worldview, ultimate presumptions, and individual experience). A model includes a subjective representation of certain world aspects, which is subsequently converted into a thought or interpretation. *Language*, then, serves as a means to describe and communicate such thoughts and interpretations. In some cases, this process can have far-reaching consequences. According to Pietro Redondi, in his seminal book *The Assayer*, published around 1623, "Galileo proposed a new language in physics. This was not at all a question of neologisms, but rather one of new definitions and rules . . . it went from a language modeled on everyday common sense to a more elaborate and analytical, richer and more rigorous language" (Redondi 1987). Psychologists and linguists have long recognized that language can dictate agent's conception of reality. Surely, agents use the same words, but the words may mean different things to different people. This is mainly due to the fact that, while the words one uses sound familiar, an agent's model of the world usually remains hidden. It is then easy for other people to be misled, assuming that the agent uses the same model as they do, whereas, in fact, this is not the case. This situation is linked to the crucial notion of metalanguage, which will be the concern of the following section.

3.7.2 On Metalanguage

In linguistics, similar concerns have led to the development of the so-called *metalanguage*, a language used to make statements about language (the *object language*; i.e., the object of discussion). Note that the term "meta" (which is a Greek word meaning "after," "beyond," and "a shift in level") here implies the relationship of "being about" something. Hence, a metalanguage is a language to describe another language. In the sentence *running slowly*, e.g., the verb "running" is part of the object language and the adverb "slowly" is part of the metalanguage. As a consequence, it will be a mistake to treat a term as part of the object language when it is, in fact, a part of the metalanguage (Audi 1996). When one says, e.g., that *This sentence is false*,[20] one is treating the term "false" as being part of the object language, whereas the term is actually part of the metalanguage.

The idea of a metalanguage is not limited to linguistics, but has been considered in several other domains such as mathematics, logic, physical sciences, and computer engineering (Lu 1988; Gamut 1990; Hopcroft et al. 2001; Zizzi 2007).[21] Indeed, while language is a prime tool of thought and communication, a metalanguage helps develop domain-specific languages. Terms like "theorem," "variable," "multiply," and "inconsistent" are part of the metalanguage of mathematics. In an analogous manner, terms such as "proposition," "premise," "conclusion," "true," and "false" are part of the metalanguage of logic. There is, e.g., a difference between the proposition *A* (true or false) and an agent's assertion that *A* is true or false. In this case, *A* is part of the language, whereas the assertion about *A* belongs to the metalanguage. The matter is further discussed in Chapters 4 and 5 in a stochastic reasoning setting. Madeleine Wolff-Terroine (1976) emphasized the disadvantages of natural language for medical data processing and the necessity of creating an artificial language or metalanguage. Terms such as "conserved," "balanced," "probable," and "uncertain" are parts of the metalanguage of physical sciences. Moreover, the well-known Feynman diagrams (Mattuck 1992) constitute a powerful quantum physics metalanguage. It is surely not a surprise that the important role of metalanguage in physics was well understood by Niels Bohr, among other eminent scientists (DePauli-Schimanovich et al. 1995).

3.7.3 Niels Bohr's Epistemology of Modern Science

Epibraimatics appreciates that fact that when it comes to the meaning of the datasets and equations involved in the IPS approach and the description of the results obtained, scientists and engineers essentially use the same ordinary language that all humans use. How everyday language relates to the scientific description of the world is a major issue that has been addressed by philosophers and scientists, among the most notable of them being Martin Heidegger, Ludwig Wittgenstein, and Niels Bohr. Section 2.3 discussed Wittgenstein's ideas in an IPS setting. Wittgenstein maintained that there cannot be constructed a perfectly objective language by means of which truth can be discovered. The work of Heidegger focused on human *beingness*, i.e., an agent's ability to exist in the world as determined by the choices the agent makes. According to him, "being there" in the world (*Dasein*) is not the same as "being conscious." Heidegger's fundamental insight was that, as human beings, agents cannot really separate language and

[20] This is widely known as the *Liar paradox* (Barwise and Etchemendy, 1987).

[21] See, also, the metarules of shadow epistemology (Section 1.4.2).

reality. Niels Bohr was a member of this rare group of people we call "global thinkers." Most thinkers contribute *locally*, i.e., their work focuses on a small disciplinary scale. Although there are cases in which a local contribution is fundamental, in most cases it consists in repeating techniques that are well known in other fields but are presented in a way that fits the background, qualifications, and other characteristics of the scientific "tribe" they address (see, also, Section 1.8.4). There are, also, those precious few thinkers who contribute *globally*, whose force of mind and power of expression transcend disciplines and "turfs." Epibraimatics teaches us that, at a minimum, one must learn to listen globally and tolerate locally. As a global thinker, Bohr brought to our attention the complementarity of object language and metalanguage. His emphasis was on the proper use of language, endlessly searching for the right words to communicate adequately his ideas. It was Niels Bohr who famously declared: "We are suspended in language so that we don't know which is up and which is down."

Behind Bohr's statement lies his concern that a human agent is so deeply embedded within the common language of every-day life that fails to recognize that this language routinely employs concepts that are linked to the large-scale world, having no meaningful relation to the small-scale world of quantum physics. Then, one is dealing with the paradox of describing quantum phenomena in terms of idealized classical concepts. For example, a quantum particle is beyond human experience, and as such, it is neither a wave nor a particle. Instead, physicists substitute the appropriate classical concept, wave, or particle, as and when necessary (Baggott 1993). Bohr's perspective that language operates by pointing to entities of the world under consideration is general and applies in many aspects of human inquiry. Jacques Derrida, e.g., has built a so-called "deconstruction" system of literary criticism on the notion that whatever language expresses an idea, it changes it (e.g., Caputo 1997). To paint with a broad brush, in many problem descriptions the use of language refers to the world of everyday experience, whereas scientific theories and experiments may be associated with a different world representation. It is then possible that the current vocabulary used in many fields is outdated and inadequate to describe the phenomena associated with the particular problem. In the field of environmental hydrology, e.g., one observes a considerable disassociation between the vocabulary of the field and the actual phenomena it is supposed to represent. Under the circumstances, one should not be surprised by the appearance of environmental experts like John L. Wilson, who has long time envisioned himself as *John the Baptist* of environmental hydrology, trying to prepare the field for the new era in the language of the old (Wilson et al. 2005). It has become clear by now that despite its great significance, language is not as precise or as complete as one would like it to be. Scholars working in cutting-edge research increasingly consider the possibility that a new language may need to be invented that better captures the essence of the new problems confronting them. F. David Peat, e.g., argues that the modern worldview deals in process, transformation, and flux, whereas European languages deal with the world in terms of nouns and concepts. What is needed, in Peat's view, is a true process-language that is rich in verbs and in which nouns occupy a secondary, derivative place. According to Peat (2002), Western science has now entered a new domain where noun-based languages may not be appropriate anymore, which means that linguistic certainty is another of those illusions of early twentieth century that may have to be dropped.

3.8 When Truth Is Bigger Than Proof

This section focuses on the fundamental distinction between formal (mathematical) and interpretive (physical) knowledge, and its significant consequences in real-world IPS. The movement between the practices of mathematical modeling and in situ experience provides rational agents with a perspective from which to interpret as significant the gaps in the current worldview. Before proceeding, we must recall that the frequent confusion between "truth in Nature" and its possible "mental representations" is at the root of many debates in philosophy and science. Otherwise said, while an intellectual debate concerning the relative value of different representations of truth in people's minds (often linked to different philosophies) makes sense and is even necessary, debates that bring mental representations against the truth of Nature are rather meaningless, especially when the latter is unknown. It is easier to generate propositions that look interesting (a rather subjective notion, in the sense that a proposition that is interesting to some people may not be so to others) than to discover propositions that are truths of Nature (in the sense that they concern all people).

3.8.1 Ignoramus vel Ignorabimus

That is, we do not know or we shall never know? Part of the fear of the unknown is due to the fact that the boundaries between the known and the unknown, and between the knowable and the unknowable, are not explicit but rather convoluted. The boundaries between reality and human consciousness apparently lie between dimensions, rather than having a specific dimension. No wonder, then, human agents have a hard time to comprehend the world around them, or why, in many cases despite the large numbers of data, reality still is neither sufficiently understood nor predictable.

As a matter of fact, the great dilemma of the unknown vs. the unknowable has challenged generations of mathematicians, scientists, and philosophers. The attempt to provide a resolution to this dilemma has marked the lives and works of two of the greatest thinkers of all times: Aristotle who claimed that the world does not harbor a hidden reality (agents can trust their perception powers to discover all aspects of reality), and Plato who believed that we shall never know reality exactly as it is (what agents can hope for is useful mental constructions of reality). In most cases, scientific inquiry is basically a matter of interplay of Platonic and Aristotelian views of speculation and theorization corroborated by observation and experimentation. Beyond any doubt, mathematical models have been proven to be currently the most powerful of the models used in scientific inquiry and IPS. However, a key question remains the crucial relationship between models of reality (like mathematical models) and reality itself. In other words, what one can know about Nature with the help of mathematical models, and what one can never know. This being the case, some important distinctions should be considered at the very outset between the idealistic mathematics and the realities of Nature.

3.8.1.1 The End of a Dream

Mathematical reasoning begins with certain statements taken to be true without benefit of proof (the so-called "axioms"), and then employs the tools of logical inference to deduce new true statements (theorems) from the axioms. If, given a set of axioms, it can be shown that both a statement and its negation can never be derived by logical deduction from these axioms, the latter are termed "logically consistent." In this deductive albeit idealistic sense, mathematics was viewed as a perfect tool, to the point that in the 1920s the great mathematician David Hilbert enthusiastically claimed that every possible mathematical statement could be settled, true or false. Unfortunately for Hilbert, in the 1930s the work of the brilliant young mathematician Kurt Gödel[22] demonstrated that every consistent logical system contains propositions that are really true but undecidable (can be neither proved nor disproved) within the system, i.e., there is no way to determine whether any given proposition is or is not decidable (Gödel 1992). In addition, in 1935 Alan Turing essentially showed that there is no systematic procedure for deciding the provability of any given proposition.[23] As Eric Temple Bell noticed, "It gradually appeared that mathematics is not the blurred image of an eternal and absolute truth, but is a technique devised by human beings to serve human needs."

Regarding physical knowledge, the relevant concerns include matters of characterizing meaning and providing substantive understanding. In this milieu, open system elements (conceptual, technical, and subjective uncertainties; limited data; and auxiliary assumptions) and human factors (thinking modes, decisions, and goals) enter the inquiry process in a central way that deeply affects the essence of knowledge reliability. Using a metaphor, the "model–reality" link may be exemplified in terms of the "map–territory" relationship.

3.8.1.2 Truth Is Bigger Than Proof

In light of the above, one can claim that *truth is bigger than proof*. Knowing how to prove something does not necessarily mean that one understands the deeper meaning of what one has proved.[24] Mathematics is riddled with logical holes and gaps as any

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[22] Gödel's theorem is also known as the incompleteness theorem. G.H. Hardy said that, "if there was not for the incompleteness theorem we should have a mechanical set of rules for the solution of all mathematical problems, and our activities as mathematicians would come to an end."

[23] Gödel showed that there must always be some undecidable propositions and Turing argued that there is no systematic way for determining whether any given proposition is or is not decidable.

[24] The incompleteness of mathematical reasoning implies that there is an eternally unbridgeable gap between the two: "everyday truth" is a larger concept than "mathematical truth".

other human intellectual undertaking and, as a consequence, mathematics could not be able to claim a degree of truth greater than that claimed by natural sciences. Wittgenstein summed it up as follows: "A mathematician is an inventor, not a discoverer." From a similar perspective, Gödel's work is a mathematical formulation of Wittgenstein's main conclusion that language cannot capture all there is in the world. Sure enough, the situation raises a number of questions concerning the logical relationship between mathematical models of the natural world and the world itself. Paul A.M. Dirac observed that, "The mathematician plays a game in which he himself invents the rules, while the physicist plays a game in which the rules are provided by Nature" (Dirac 1938–1939: 122). Correspondingly, an IPS approach should develop around a relationship between mathematics and Nature that is at least threefold:

At the *conceptual* level: Truth as understood in mathematics and the same concept as experienced in everyday terms are often different.

At the *methodology* level: Mathematical reasoning focuses on logical consistency and offers no criterion to claim that the initial knowledge (axioms) is really knowledge.

At the *epistemology* (*knowledge-theoretic*) level: There are limits in the precision of certainty due to boundaries imposed by the investigator as a thinker.

As noted earlier, mathematical reasoning begins with initial knowledge (the axioms of the logical system) and employs the tools of deductive inference to generate new true statements (theorems) from the old ones. As far as in situ IPS is concerned, one problem with this reasoning is that it focuses solely on logical consistency and provides no criterion by which one can claim that the initial axioms are really knowledge. That is, they may or may not accord with the way things are in situ. Moreover, in some cases of deductive argumentation, there is no consensus about what logical operations can be used in creating new knowledge. There are limits in the precision of certainty achieved by mathematics that are due to boundaries imposed by epistemic concerns, i.e., by the investigators themselves as rational thinkers. Mind plays an essential role in the entire measurement chain, whereas the solution of an in situ problem is a reasoning process in which human decisions and goals enter in a central way. Hence, this process cannot be dry and technical as a purely mathematical procedure, merely involving abstract relationships and logical consistency. Before leaving the section, I would like to remind the readers that during his 1964 address given at the ancient Pnyx Hill of Athens, Werner Heisenberg confessed that mathematics cannot describe the human experience of patterns (Plato's archetypes): "Whatever the explanation of these other forms of understanding may be, the language of the images, metaphors and similes, is probably the only way to approach them" (Heisenberg 1970: 45).

3.8.1.3 A Reasonable Compromise

While most schools of thought share the above concerns about the bounds of scientific method and the limits of mathematics, they also admit, excluding a certain version of postmodernism, that the search for truth (the process by means of which this ultimate goal is sought) has been a vital component of human inquiry, and that a key contribution of scientific reasoning (based on mathematical tools) is that it has provided partial yet very useful representations of Nature, and has successfully solved numerous important problems of the real-world. With time, the existing representations are replaced by new and improved ones, in the sense that the latter offer better explanations of observed phenomena and generate more accurate in situ problem–solutions.

On the contrary, radical postmodernism has exhibited an uncompromising attitude toward human inquiry, rushing to attack the possibility of truth, to undermine all knowledge and achievement, and to embrace irrationality and a far too passive "anything goes" perspective. In Bruno Latour's words: "...a certain form of critical spirit has sent us down the wrong path, encouraging us to fight the wrong enemies and, worst of all, to be considered as friends by the wrong sort of allies..." (Latour 2004: 231). Postmodernism claims that any perception of reality and any belief system, even those containing serious internal inconsistencies, are equally valid. Sadly, postmodern nihilism entered the domain of paranoia when its devotees concluded that nothing is real, including physical objects, living organisms, and human existence itself.[25] If not careful, the species of radical postmodernists will eventually cease to exist as a result of them falling victims to diseases, natural disasters, accidents, and other earthly events, the existence of which they reject in the first place.

3.8.2 The Case of Multidisciplinarity

Multidisciplinary matters are discussed in various parts of this book, and for a good reason. Multidisciplinary studies present an additional complication in problem-solving due to the disparity in perspectives concerning (a) the collection, development, and communication of the relevant KBs, and (b) the assessment of their reliability (Klein 1996; Jakobsen et al. 2004; Lele and Norgaard 2005). In certain cases, scientists and engineers may view the conceptual frameworks, assumptions, methodologies, and techniques outside their own discipline with considerable discomfort (Eigenbrode et al. 2007). It is possible that a data acquisition technique and/or a reliability assessment method that are acceptable in one discipline to be looked upon with suspicion in another. For example, the triangulation method that is commonly used in social sciences (Denzin 1970) may not be considered adequate in physical sciences. Under these circumstances, it is very difficult for scientists from different disciplines to establish an adequate form of communication so that they can study a multidisciplinary problem with efficiency and reach an integrative problem–solution. Instead, the study contributors prefer to keep a distance from each other, and to avoid being involved in discussions that could challenge the dogmas and ultimate presumptions of their disciplines, often resorting to the

[25] The disastrous effects of radical postmodernism in higher education have been discussed in Chapter 1.

calculated politeness metarule (Section 1.4.2). Figuratively speaking, it is like someone standing outside a teashop and waving to people sitting inside as if that is a sufficient form of communication or even more so an adequate expression of knowing what the others are doing inside that teashop.

In a genuine multidisciplinary study, each IPS participant must contribute something different, significant, and original. In order to understand someone, you must be someone. Multidisciplinarity does not cancel the individual characteristics of each participating discipline. On the contrary, it encourages and enhances individual characteristics and differences in the spirit of nonegocentric individualism (Section 1.11). The latter is a vital characteristic of IPS, because its opposite, egocentric individualism, has been responsible for certain negative developments in scientific inquiry (including narrow mindedness, "convenient" manipulation of facts, favoritism, turf wars, greediness, and even scientific dishonesty). I will conclude this section with a last, not totally uncontroversial, argument. For reasons having to do with their own welfare and the proper functioning of the society, people must be able to generally assess the value of the different kinds of data presented to them – without necessarily being experts in the relevant knowledge domains. Some thinkers believe that *intelligent sciolism* (quality shared by people who are aware of imperfections in their understanding of the world and act accordingly) can help one obtain a satisfactory comprehension of many issues, form sound opinions about their societal consequences, and make a sound decision (e.g., one does not need to be a medical doctor in order to have a justifiable opinion about abortion). In this line of thought, it should be useful if disciplinary experts involved in the solution of a real-world problem understand the basics of the other disciplines, at least at the intelligent sciolism level. Integrative problem-solvers should be able to bring in experts from different disciplines to fill skill gaps when necessary, recognize when leading-edge theory and methods are involved, and when new and substantive findings rather than trivial results are generated (Bammer 2005).

3.9 The Structure of Knowledge

Chapter 1 introduced the readers to the vast territories of knowledge in its various forms and shapes. Here, we revisit this very important topic in the light of Epibraimatics ideas.

3.9.1 About the Way Knowledge Is Claimed and Constructed

There are a number of interesting issues related to the way knowledge is claimed and constructed in the general IPS setting. The *theoryladenness* of knowledge acquisition and description is discussed in some detail in Chapters 1, 4, and 6: There are no theory-free scientific data or event descriptions. Many fundamental laws could not have been derived purely from empirical data analysis.

Verificationism, the notion that any meaningful proposition should be empirically tested, collapsed rather quickly after it was proposed by logical positivists.[26] There are profound reasons for this collapse and have been discussed in the relevant literature (Misak 1995; Stokes 2007). One of the main reasons is that verificationism falls of its own criteria for meaninglessness since its suggestion that a proposition is only meaningful as far as there is a means for its verification is in itself neither analytic nor can it be tested by empirical means.

If the readers allow a metaphor, putting testing before meaning is like putting the cart before the horse. Meaning should be prior to testing; otherwise one can neither set up an appropriate test nor be sure what one is testing. In fact, a lot of modern science is conceptual and untestable in a straightforward empirical manner (e.g., theoretical entities like electrons and quarks play a major role in science but cannot be seen). Stephen G. Brush offers an interesting insight about the experimental studies of Brownian motion in late nineteenth–early twentieth century (Brush 1968: 2):

> Three-quarters of a century of experimentation produced almost no useful results, simply because no theorist had told the experimentalists what quantity should be measured!

Indeed, observations and experiments without a sound theory to support them and a rigorous methodology to express them are vulnerable to misunderstanding, misuse, and caricature. One should always keep in mind that knowledge is a conscious creation of the human mind. Some other issues, which are directly related to the theory of knowledge (mind–brain problem), have been discussed in Section 3.3.

3.9.2 Epistemic Standards of Knowledge

Since not all KB generated during an in situ study are necessarily correct, recourse to epistemic standards evaluating the "grounds of knowledge" is unavoidable. Thus, the role of epistemology is here linked to the questions of knowledge reliability[27] and internal consistency.[28] Cognition, on the other hand, is concerned with the mechanisms of acquiring knowledge, including perception, intuition, and reasoning. The contribution of cognition in the development of an adequate knowledge structure is to identify basic knowledge assimilation, belief forming, and other IPS elements, which are then examined (for their reliability, consistency, etc.) by means of the evaluative standards of epistemology. In the knowledge reliability setting, matters of considerable importance include matters of interest to brain and

[26] This was a group of scientists-philosophers who formed the so-called "Vienna Circle" in early twentieth century. The best known among them were Moritz Schlick, Otto Neurath, and Rudolph Carnap.

[27] The issue of knowledge reliability and some historical background were first introduced in Chapter 1.

[28] See, also, Section 3.6.4 above.

neuropsychological sciences, including the so-called “common sense,” “cognitive dissonance,” and “metacognitive experience.”

Common sense is a popular term widely used to express ordinary good sense or sound practical judgment. Generally, common sense is defined as a set of supposedly sound and prudent judgments based on a simple perception of the situation or facts. For David G. Myers (2007), in everyday life common sense is a double-faced Janus: Helpful or perilous. This is a matter of considerable controversy that goes back to the times of King Solomon. The king clearly favored evidence-based rationality over gut instinct, when he famously uttered: “He is a fool that trusteth his own heart.” Common sense opinions, judgments, and beliefs are usually shared by members of a certain group (social, scientific, political, or religious). As such, common sense is a learned mode of thinking shared by group members, which invariably leads to common interpretations and conclusions. It is closely associated with human experience and hardly ever extends beyond it. Hence, there are common sense views about human scale phenomena (poverty, marriage, and human rights), but there is no commonsensical argument about the big bang phenomenon occurring at the megascale or about microscale quantum phenomena.

Identifying knowledge items that can be characterized common sense is not always an easy affair. History has taught us that what at a certain time was considered common sense later was proven to be pure nonsense, e.g., the once common sense view that earth is flat. Unfortunately, common sense has been widely abused, especially when other arguments have been exhausted, in which case common sense is fallacious, being a form of *argumentum ad populum*.[29] Many common sense judgments and propositions should be considered *cum grano salis*, because they are often blinded by prejudice, unstated premises, hidden assumptions, and vested interests. This is valid for small or large groups of people. According to Lathel F. Duffield (2007: 63), “Americans who are not aware of the depth and assumptions guiding their thinking see the world in only one way – the American way.” Similarly, the elites of Eurocrats are convinced that they know the solution to all Europe’s problems, and will probably continue to do so regardless of the harm they cause (Haller 2008).

In sciences, common sense often conflicts with experimentally verified results. As a consequence, the value of common sense in scientific inquiry is highly controversial. Einstein’s famous definition was that, “Common sense is the collection of prejudices acquired by age eighteen.” Scott O. Lilienfeld (2006: 46) warned us about “The public’s erroneous belief that common sense is a reliable guide to evaluating the natural world.” Scientists have realized long time ago the inadequacy and even danger of relying on common sense and gut instinct during the process of scientific inquiry. K.C. Cole’s poignant comment is indicative of the situation (Cole 2003: 43): “If there’s one quality that’s sure to get a scientist into trouble, it’s common sense. Over and over again in the history of science, common sense has been exposed as a lousy guide to truth . . . The unsettling truth is that Nature doesn’t give a hoot what humans think is ‘common sense’.” Massimo Piattelli-Palmarini

[29] Appeal to the people.

(1994) carefully reviewed a series of cognitive illusions due to common sense thinking that demonstrated how remote from genuine scientific inquire is the sort of "quick and dirty research" advocated by pseudo-practical investigators (see, also, Section 2.5.2). Most multidisciplinary studies agree that minimum prerequisites for common sense to be a valid form of knowledge include: It should be consistent with current knowledge; free of prejudices, subjective bias, and vested interests; and open to constructive criticism in terms of the evaluative standards of epistemology.

3.9.3 Psychological Issues of Knowledge

Cognitive dissonance is a psychological term that describes the motivational mechanism underlying an agent's reluctance to admit of being wrong and to refuse openness to criticism and possible change (Festinger 1957; Aronson 1969). Human agents in a state of cognitive dissonance typically tend to notice data and evidence that confirm their views and beliefs, whereas, at the same time, they ignore data that disconfirm their views and convictions. Dieter Frey (1982), e.g., studied how people seek out information that is consonant rather than dissonant with their own views. This and similar studies have shown that cognitive dissonance may be a serious barrier to informed choice. Cognitive dissonance inhibits processing of knowledge, which can be a serious matter when aiming at communicating risk information (Steckelberg et al. 2005). In relation to the above, Carol Tavris and Elliot Aronson noticed that (Tavris and Aronson 2007: 13), "With the breakdown of the firewall between research and commerce, scientists' intellectual dependence is being whittled away. Many scientists, like plants turning toward the sun, are turning toward the interests of their sponsors without even being aware that they are doing so. When investigators have compared the results of studies funded independently and those funded by industry, they have consistently uncovered a 'funding bias'."

Metacognitive experience refers to the ease or difficulty with which data are brought to mind and thoughts are generated, and the fluency with which new data can be processed as well as emotional reactions to that data. As experimental studies have shown (Schwarz et al. 2007), "Once memory for substantive details fades, familiar statements are more likely to be accepted as true than to be rejected as false. This familiarity bias results in a higher rate of erroneous judgments when the statement is false rather than true." This essentially means that humans tend to rely on familiar knowledge that already exists in their minds rather than on recently acquired information, a situation that has profound effects on an agent's reasoning process during problem-solving. Therefore, the IPS approach should be concerned not only with the content of the information available but with the metacognitive experience as well. In the case that there are good reasons to favor memory-recall (associated, e.g., with pre-existing general knowledge), a certain kind of quantitative analysis based on stochastic reasoning may be appropriate, whereas in the case that metacognitive experience favors new and site-specific data, a different kind of quantitative analysis based on Bayesian adaptation may be a better choice

(Chapters 5 and 6). On a relevant note, a large amount of evidence points to the direction that an IPS process has important cognitive elements that are performed by the use of organs of the brain and the nervous systems. Hence, as noted earlier, the IPS process should include an essential brain and behavioral dimension.

3.10 A Fusion of Ideas and Functions: A Man's Ithaca

Epibraimatics' viewpoint is that a reliable means to problem-solving is constructive criticism, which implies that in order to understand a concept or a method, one must be able to look at them from different perspectives (including science, philosophy, and mathematics), and to be able to interpret and connect them to related concepts and methods.

3.10.1 Thinking in Literary Terms

Accordingly, basic IPS principles and techniques emerge from the fusion of ideas and functions, some of which are originated in brain and neuropsychological sciences. The fusion involves a novel interpretation of these ideas and functions that is fruitful in the study of natural systems, and the efficient solution of important problems. Every step of the fusion takes advantage of epidemology's high practical value that helps clarify ideas, brings agent's presumptions to critical scrutiny, and removes misunderstandings. On occasion, the fusion may imply thinking in *literary* terms about scientific IPS. This intriguing possibility is explored in various parts of the book.

A prime feature of this worldview is *nonegocentric individualism*: a state of delivering one's values and purpose without being self-centered in value thinking (Section 1.11). Epibraimatics is dealing with multidisciplinary problems, managing multiple settings, assessing the credibility and consistency of different knowledge sources, and the development of rigorous IPS frameworks. Its nonegocentric individualism sharply distinguishes Epibraimatics from other kinds of inquiry that also attempt a deeper look at the brain's structure but with the explicit goal of building intelligence machines (Hawkins 2004). Epibraimatics should be also distinguished from artificial intelligence technologies like neural networks,[30] which are based on computer architectures that are syntactic engines, not semantic ones (Dennet 1984); they are irrelevant to human cognition's main objective of symbol interpretation (Macnamara 1994); and they are unable to innovate (go beyond what is already known). Section 3.1 indicated that Epibraimatics' aim is not to copy

[30] These consist of a system of computer programs and data structures that approximate brain's phenomenological operations. The computer processors, e.g., are connected in a manner suggestive of connections between brain neurons, they respond in parallel to a set of input signals given to each, and they are supposed to learn by trial and error.

physical brain activities in a mechanical manner, but rather to develop stochastic reasoning that satisfies their mental functions (prescriptivity, intentionality, complementarity, and adaptation) under conditions of in situ uncertainty.

3.10.2 Licentia Poetica

Before further immersing ourselves into specified problem-solving matters, the readers may excuse yet another diversion by resorting to Seneca's *licentia poetica*. Section 1.1 suggested intriguing parallels between modeling and performance poetry. The readers may recall that a central thesis of Epibraimatics is that the *search* for Truth[31] is as important as the Truth *itself*. Man's fascinating journey in search of Truth was glorified by Constantin P. Cavafy's celebrated poem:

Ithaca
(Constantine P. Cavafy, 1911)

When you you set out on your journey to Ithaca,
pray that the road is long,
full of adventure, full of knowledge.
The Lestrygonians and the Cyclops,
the angry Poseidon -- do not fear them:
You will never find such as these on your path,
if your thoughts remain lofty, if a fine
emotion touches your spirit and your body.
The Lestrygonians and the Cyclops,
the fierce Poseidon you will never encounter,
if you do not carry them within your soul,
if your soul does not set them up before you.

Pray that the road is long.
That the summer mornings are many, when,
with such pleasure, with such joy
you will enter ports seen for the first time;
stop at Phoenician markets,
and purchase fine merchandise,
mother-of-pearl and coral, amber and ebony,
and sensual perfumes of all kinds,
as many sensual perfumes as you can;
visit many Egyptian cities,
to learn and learn from scholars.

Always keep Ithaca in your mind.
To arrive there is your ultimate goal.
But do not hurry the voyage at all.
It is better to let it last for many years;
and to anchor at the island when you are old,
rich with all you have gained on the way,
not expecting that Ithaca will offer you riches.

Ithaca has given you the beautiful voyage.
Without her you would have never set out on the road.
She has nothing more to give you.

And if you find her poor, Ithaca has not deceived you.
Wise as you have become, with so much experience,
you must already have understood what Ithacas mean.

In the poem, the ultimate goal (the Truth) is the Homeric island of Ithaca. Man's journey toward this ultimate goal is portrayed as his life's Odyssey. The inner meaning of the journey is the central theme in Cavafy's poem, just as a creative and intellectually experienced solution process is of vital importance in IPS thinking. Ithaca is our reason for the journey, but if we do not appreciate what the journey has to offer us (if we rush past the markets and the merchandise, do not improve our knowledge and accumulate valuable experience, do not pause to feel the summer mornings and smell the perfumes, and do not become better human beings), will our

[31] In a problem's context, the truth is increasingly approximated by its solution (see the teachings of the Eleatic school in Section 1.1).

senses even know what Ithaca is when we finally arrive? Will we understand the Truth when we finally discover it?

Epibraimatics is in par with the view that scientific inquiry is currently the best means available to humans to understand the natural world and themselves as part of this world. However, Epibraimatics does not view science merely in the somewhat degraded sense of the term (algorithmic, computational, and experimental manipulation), but in its deeper meaning that refers to *knowledge* concerning Man and its environment. In this sense, Man is at once the *object* and the *subject* of this knowledge, since he is the only being that seeks knowledge, in general, and *a* knowledge of himself, in particular. As we have seen in previous sections, a brain cannot act if separated from the mind and consciousness, and a mind can only function in terms of brain activity.

3.10.3 The Augsburg Man

Epibraimatics argues that since intelligence is an internal property of the brain, it is plausible to look inside the brain to understand what intelligence is and how it provides meaningful and innovative problem–solutions. This rather contradicts the artificial intelligence idea that the brain has nothing to teach us about the mind. Epibraimatics does not separate a problem–solution, viewed as a mental construction, from the evolutionary functions of brain activity (teleology, adaptation, consciousness, and mental causation). Given a mathematical model representing certain aspects of a geophysical system, e.g., a solution that assumes that the model is a mental construct describing incomplete knowledge about the system can lead to more adequate representations of the in situ situation than an ontic solution based on mainstream techniques that misinterpret the model as an exact representation of reality and focus on form manipulations (Christakos 2004, 2005). According to many neuroscience experts, mental functions are caused by brain mechanisms that go on at the neuronal or modular level. But, at the same time, they are emergent states that are realized in the system consisting of neurons (Searle 2003). This is in the same way that physical processes at the macrolevel emerge from elements at the microlevel (e.g., temperature is the result of many interacting particles in motion), but the former have higher-order features that are different from the features of the latter. This perspective is similar to the views of Crick and others (Section 3.2.3).

The IPS process is interested in the significant role of the conscious scientist within the limits of the real-world and not merely in the conventional solution of the abstract mathematical model representing the situation. The readers may imagine themselves as the man in Augsburg's sixteenth century woodcut, trying to extend his head beyond the edge of the familiar world, in an apparent effort to escape the limitations imposed by it and view other dimensions of reality. To put it in slightly different words, Epibraimatics favors an IPS approach that views the conscious scientist and the problem–solution as an integrated whole. This is an introspective approach beyond the mere application of mathematics. The approach seeks to "humanize" the quantitative solution by replacing pure mathematical mechanization with intellectually experienced reasoning. In this setting, IPS does not equate the truth of a mathematical statement about the in situ problem with its formal provability. A considerable part of mathematics is viewed as a constructive mental function of humans (that does not merely consist of formal activities), by means of which deep properties of existence are revealed and applied. The investigator attempts to establish a rigorous formulation of synthetic reasoning that pertains to establishing a sound framework of real-world IPS. Underlying the synthetic reasoning is an epistemology that assumes that the models developed by mental functions describe incomplete knowledge about aspects of reality rather than reality directly;[32] focuses on conceptual mechanisms of critical thinking without assuming any fundamental separation of mind and reality; attempts to reconcile the antagonistic demands of observation and interpretation; and proposes certain postulates to express conscious potentialities and prescriptive cognitive features, using them to generate a reality representation (problem–solution) that accounts for connections between the existing core knowledge and site-specific data. Generally speaking, in an IPS setting the epistemology investigates the relationship between mathematical entities (signs, symbols, formulas) and natural science entities (phenomena, systems, processes), and it is concerned with the relation between the general and the particular. "To know" means to relate a particular experience in the world to a concept or law. As is the case with any kind of human activity, there is a certain amount of uncertainty involved in this sort of inquiry as well, which may have an ontic character (complexity of the underlying natural mechanisms and patterns) or an epistemic character (incomplete knowledge).

3.10.4 Reviewing Old Ideas in New Contexts

Reviewing old ideas in new contexts has been successful so regularly that people have come to expect it to work. This is essentially the meaning of Lawrence M. Krauss' comment about the situation in physics and its great successes: "One sees the same concepts, the same formalism, the same techniques, the same pictures, being twisted and molded and bent as far as possible to apply to a host of new situations . . . This might seem to be a pretty timid, even uncreative approach to unlock Nature's secrets, but it isn't . . . It often requires great creativity, too, to see how existing ideas might apply to new and unusual situations . . . It is this creative plagiarism that makes physics comprehensible, because it means that the fundamental ideas are limited in number" (Krauss 2007: 69–70). In fact, it is not uncommon in scientific investigations to start from different origins and to end up with similar mathematical formulations of what otherwise are different physical situations. Epibraimatics is aware of the fact that in many instances of scientific inquiry, the *interpretational viewpoint* can make all the difference: Using different

[32] Interestingly, an agent must use a biased and imperfect brain to correct and improve its performance.

strains of thought, drastically different meanings may be assigned to the same mathematical formulations derived on the basis of the same dataset. According to Arthur I. Miller, Hendrik Lorentz was unable to discover special relativity because he was stuck in outdated modes of reasoning (Miller 2001: 240–241). Albert Einstein and Henri Poincaré came the closest to discovering special relativity. They had at their disposal the same experimental data and proposed identical mathematical formulations to explain them. But Einstein inferred a *meaning* Poincaré did not. Einstein interpreted the mathematical formulation as a new theory of space and time, whereas for Poincaré it was a generalized version of Lorentz's electron theory. Let us consider another example. The mathematical formalism of "entropy" arises in various scientific disciplines, in which, though, it has been assigned very different interpretations (Christakos 2000: 124). In 1896, the term was introduced by Boltzmann in the kinetic theory of gases to measure disorder in terms of the probabilities of molecular arrangements. While studying communication engineering problems, Shannon derived in 1948 a working definition of syntactic information which, when translated into mathematical symbols, was identical to the Boltzmann entropy function. While the mathematical formalism is the same, from an interpretational viewpoint the two entropies are drastically different (Chapter 7).

Before ending this chapter, I would like to notice that the thoughts expressed in the preceding sections are the result of a strong belief that when rigorous methodology, intellectual debate, philosophical continuity, and social maturity are lacking in a discipline, the latter shows a serious difficulty to rank intellectual contributions, and distinguish between science and pseudoscience, profundity and superficiality, truth and ideology. This is a weakness that festers and worsens with time. Claims to the opposite either show plain ignorance or are calculated to distract attention from thinkers not serviceable to the plans of the power holders.

Chapter 4
Space–Time and Uncertainty

Space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind union of the two will preserve an independent reality

A. Einstein

4.1 The "Canvas Vs. Parenthood" Dilemma

Let us start with a metaphor: The matter of space–time may be represented by the so-called"Canvas vs. Parenthood" dilemma (Musser 2006): Is space–time like a canvas that exists whether or not the artist paints on it, or is space–time akin to parenthood that does not exist until there are parents and children? A related question is the "asymmetry of time": Is time's asymmetry a property of states of the world rather than a property of time as such? One could even consider the far-flung connections between the geometry of space–time and the distribution of attributes within space–time: Can this distribution influence space–time and vice versa?

4.1.1 Making Progress One Funeral After Another

The previous chapters brought to the readers' attention the fact that real-world systems and their attributes hold space–time relationships among each other in a way that reflects the underlying mechanisms of Nature. All biological systems, e.g., are spatiotemporally restricted. Nonetheless, these elementary facts of life do not resonate with certain scientists of the purist type. In the mainstream epidemiology paradigm, as some have criticized and others celebrated, space-time eludes proper presentation. The mainstream paradigm lacks a geometric conception of space, and it only possesses an empirical one that focuses on a single space point at a time, thus smashing the space–time continuum into small pieces. Generations of epidemiologists have been taught that composite space–time is an insignificant aspect of an epidemic study. This is, in effect, yet another case of egocentric denial of reality and

G. Christakos, *Integrative Problem-Solving in a Time of Decadence*,
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progress (Section 1.11). It seems that epidemiology is one of those disciplines in which progress is made one funeral after another. Real progress is possible when the generation of scientists that has made an investment on status quo dies off and the new generation is less biased. Fortunately, there are signs that this egocentric complacency is already disturbed by a younger generation of scientists worldwide. These scientists have decisively cut the "umbilical chord" with the old guard of western epidemiology, a move that has led to a number of insightful space–time epidemic studies (e.g., Kuo et al. 2009; Bossak and Welford 2009).

An agent's epistemic condition is basically twofold: in most in situ situations, the attribute's variation is neither completely known nor completely unknown to the agent. Instead, an agent's knowledge of the attribute lies in between these two extreme situations. The "known" space–time component includes an appreciation of the attribute's dependence *structure*, whereas the "unknown" component relates to the multisourced *uncertainty* of the attribute distribution. An appropriate model of the attribute should, therefore, account for these space–time components of attribute representation as well as for their relationships and interactions. Assessing the space–time dependence structure of an attribute involves a set of *coordinates* and the relevant *metric* (or distance). As we will see in this chapter, the meaning of the term "relevant" depends on the physical conditions of the situation (e.g., a physical law may be intimately connected to a specific metric, whereas the observation scale can determine the phenomenon to a considerable extent). As a matter of fact, the fundamental relationship between the nature of space–time and the laws governing whatever exists within space–time can be developed in a general setting: Space–time, which is the container of every natural system, is also the arbiter of whatever this system may be. Modern developments in physics have emerged within such a setting. This includes the theory of relativity, which showed that the presence of matter affects the space–time geometry; and the string theory, which argues that the properties of space–time (such as the number of dimensions) determine the laws of Nature. In real-world applications, uncertainty is a major factor often expressed either in terms of statistical probabilities (related to ontic features of the actual system) or by means of inductive probabilities (reflecting modeler-dependent considerations). The adequate characterization of space–time variation due to natural causes and uncertainty sources is an important matter, since it provides the necessary background for two crucial components of scientific inquiry: Prediction and explanation. For these and similar modeling purposes, Epibraimatics relies on stochastic reasoning (Section 1.2.3, and Chapters 5 and 6), which provides a solid theoretical background and powerful tools for studying the multisourced uncertainty and space–time dependency of natural systems.

4.1.2 The Sea of Space and Time

Human conceptions of space and time have a long and fascinating history that represents the power of mind's imagination. Zeno invented famous *paradoxes* that explored certain puzzling relationships between space and time. The reader may recall the *Parmenidean apology* of spatiotemporal analysis (Section 2.2.2): since humans are part of the world system they study, cannot place themselves outside their four-dimensional environment, and they cannot obtain an objective view of space–time. Chinese philosophers termed the passage of time from eternity to present as *zhòu*, and space in all directions as *yǔ*, in which case *yǔzhòu* literally means space–time. Remarkably, yǔzhòu is also the Chinese word for universe. Immanuel Kant maintained that space and time are *forms* of intuition or thought; one must distinguish between the content of space (time) and space (time) in itself. For him, time is defined as an order of succession and space as an order of coexistence. Space and time did not occupy the thought of philosophers only. The following is William Blake's poetic perspective on space–time (Damon 1988: 404),[1]

> Time and Space have no absolute existence: they are twin aspects of Eternity, as perceived by our limited senses in this world of matter. Together they constitute the *Sea of Time and Space* . . . Both Time and Space are compressible or extensible.

This imaginative perspective of space–time[2] radically opposed the accepted definitions of Blake's day (eighteenth century England), which were those of Newton's absolute space and absolute time. In this sense, Blake's 1821 painting *Sea of Time and Space* foreshadowed the leading ideas of modern physics concerning the fusion of space–time, which also opposed any Newtonian absoluteness of space and time. In his novel *The Time Machine* (1895), Herbert George Wells wrote that there is no difference between time and any of the three dimensions of space, except that our consciousness moves along it; time is only a kind of space. In modern scientific studies as well as in everyday life, important questions often arise concerning the nature of space–time. Many scientists believe that the distinction between space and time is a human creation – it is not at all sure that Nature recognizes such a distinction. While the sense of time is immediate and unreflective, the idea of time is abstract and general. Developments in neuroscience have discovered space-tracking neurons along the time axis (Hafting et al. 2005; Knierim 2007). When an agent recalls a past event, one recalls not only the people and objects relevant to the event but also the spatiotemporal setting in which the event took place, which allows the agent to distinguish the particular event from similar events.

4.2 Space–Time Domain and Its Characterization

Since ancient times the way thinking humans conceived the meaning of space and time and the role these two notions played in their environment was a subject of considerable debate and excitement. While current scientific inquiry focuses mainly

[1] Los and his sister-spouse Enitharmon are major beings in Blake's mythology; Los is by mortals named *Time* and Enitharmon is named *Space*. Thus, for Blake Time and Space are creatures like Adam and Eve.

[2] The reader may notice the similarity between the opening of Blake's statement here and that of Einstein at the beginning of this chapter.

on the Western conception of space–time (originated in the ancient Greek thought), there are other conceptions linked with different cultures that are also of significant interest and comparative value.

4.2.1 Greek and Hebrew Conceptions of Space–Time

Consider the Hebrew conception of space and time. The Hebrew notion of time is closely link to its content (e.g., the time of light is associated with day and the time of darkness is associated with night), whereas for Greeks time was an abstraction to be distinguished from the events that occurred in time (Orelli 1871). In a very real sense, for Hebrews, the content of time played the same role as the content of space played for the Greeks. For Greeks (as is for us today), space was like a great container that enclosed everything that existed (including the humans who live and move around), whereas for Hebrews it was time that played a similar role (i.e., one's consciousness was like a container that included one's whole life as it developed in time).

While the Greeks considered the form and location of what they called the "heavenly bodies" (mainly the *sun*) and in that way they determined time, the Hebrews determined time by the kind and intensity of these bodies' light and warmth, which is probably why the Hebrews called the heavenly bodies *me′oroth* (lamps) or *ôrîm* (lights); Boman (1970: 131). Hence, for both Greeks and Hebrews, sun was the most important determinant of time, but in very different ways (e.g., for the former day and light was determined by the movement of the sun, whereas for the latter by its illumination). Interestingly, Nehemiah determines the time for opening the gates of the city, "Let not the gates of Jerusalem be opened until the sun is hot," whereas an equivalent determination for Aristotle's way of thinking would be, "Open the gates of Athens when the sun stands high in the heavens." Yet for either view, the relevant question for studying space–time becomes: How and why and to what end does some phenomenon have meaning in a space–time context for people as the terms or conditions of their embodiment? In both ancient traditions, space–time was not merely a system of ideas and practices that someone engages, but a matrix of activities through which the moments of life appear as meaningful.

For Epibraimatics, space–time considerations may have important psychological and epistemological implications. Plato had made a poignant distinction between physical time (time divisible into various parts, such as days, months, and years) and psychological time (time categorized according to its various forms, such as past, present and future). Moreover, while space can be perceived externally, time can be experienced only internally (although it can be represented externally in terms of spatial conceptions, like a line continuing to infinity). Psychologists consider the spatial images as more original than the temporal ones. Things can get even more complicated when higher dimensions are considered. It is one thing to imagine higher-dimensional spaces and develop some kind of sophisticated mathematics within these spaces, and quite another thing to experience living in these spaces. Humans who live in a three-dimensional space find it impossible to comprehend how it is to be an inhabitant of a world with four or more dimensions.[3] Is the search for the meaning of space–time akin to the alchemist's vain quest for the Philosopher's Stone?

4.2.2 Space–Time Continuum

Be all that as it may, one may acknowledge that there are two aspects of space–time: One is intuitive and the other is technical. Intuitively, many thinkers argue that Nature should be describable by some space–time concept and that Nature does not really care which space–time concept people use. Because space and time are conceptually interrelated (e.g., the conception of time by the metaphor of a geometrical line), it is plausible to search for some sort of technical unification of space and time. Technically, the scientific analysis of attributes varying across space and time requires the introduction of the notion of a *spatiotemporal continuum* (or *domain*) E equipped with a coordinate system and a measure of distance. A continuum E is a set of points associated with a continuous spatial arrangement of attribute values combined with their temporal order. In other words, E may be viewed as a "region" in which physical matter exists and systems, attributes, processes, and objects occur or evolve. Within E, space represents the order of coexistence of events, and time represents the order of their successive existence. Spatiotemporal continuity implies an integration of space with time and is a fundamental property of the mathematical formalism of natural phenomena. By combining space and time into a single entity, E, a large amount of physical, biological, and social theories can be simplified and, thus, describe in a more uniform way the workings of a natural system.

Generally speaking, a *coordinate system* is a systematic way of referring to places, times, things, and events. A point in a spatiotemporal domain E can be identified by means of two separate entities: the spatial coordinates $\boldsymbol{s} = (\boldsymbol{s}_1, \ldots, \boldsymbol{s}_n) \in \boldsymbol{S} \subset \boldsymbol{R}^n$ and the temporal coordinate t along the temporal axis $T \subset R^1_{+,0}$, so that the combined space–time coordinates are

$$\boldsymbol{p} = (\boldsymbol{s}, t). \tag{4.1}$$

This means that an attribute is distributed in the space–time domain defined by the $\boldsymbol{p}$-coordinates above. Eq. (4.1) allows for several ways to "locate" a point in a space–time domain. Essentially, the only constraint on the coordinate system implied by (4.1) is that it possesses n independent quantities available for denoting spatial position and 1 quantity for denoting time instant. In view of Eq. (4.1), the symbol $X_{\boldsymbol{p}}$ generally denotes an attribute (associated with a phenomenon, natural system, and experiment) at a specified space–time point $\boldsymbol{p} = (\boldsymbol{s}, t)$. One can then write symbolically that

[3] Despite strong temptations, in this book we will not consider life in extra dimensions. At least, not until one can safely invest in real estate in these higher-dimensional spaces.

$$(\boldsymbol{p}_1, \ldots, \boldsymbol{p}_k) \xrightarrow{X_p} (\chi_{\boldsymbol{p}_1}, \ldots, \chi_{\boldsymbol{p}_k}), \tag{4.2}$$

which means that the $X_{\boldsymbol{p}}$ may assume different values $\chi_{\boldsymbol{p}_1}, \ldots, \chi_{\boldsymbol{p}_k}$ at different points $\boldsymbol{p}_1, \ldots, \boldsymbol{p}_k$ across space–time.

4.2.3 Space as a Mode of Thought

Locus enim est principum generationis rerum,[4] once said Roger Bacon, seeking to emphasize the role of place. According to Zhang Fa (1997), the entire western culture originates from geometry, from which the model of science comes. Indeed, in western cultures, space is used as the primary mode of thought (to the point that time, the other mode of thought, is considered as its image). Entities are defined in space in terms of their coordinates. The most commonly used system of spatial coordinates is based on Euclidean geometry, which was for thousands of years at the center of human inquiry and of the dominant world-views. David Hume was careful to point out that,

> Though there never were a circle or triangle in Nature, the truths demonstrated by Euclid would for ever retain their certainty and evidence.

Nevertheless, the time came when even the Euclidean system was proven not to provide an adequate representation of certain aspects of the real-world. This led to the development of non-Euclidean systems by the great mathematicians Johann Carl Friedrich Gauss and Georg Friedrich Bernhard Riemann, among several others. Accordingly, a familiar classification of the spatial coordinate systems can be made in terms of the following two major groups: The *Euclidean* group of coordinate systems that includes systems for which there exists a technical transformation to *rectangular* (*Cartesian*) coordinates (in the two-dimensional case, e.g., the Euclidean group is associated with a flat, Euclidean geometry). The *Non-Euclidean* group of coordinate systems that includes systems for which it is not technically possible to perform a transformation to Cartesian coordinates (this group is associated with a curved geometry). The readers would notice that in addition to the Cartesian system considered above, well-known Euclidean coordinate systems are the *polar*, the *cylindrical*, and the *spherical* systems. Celebrated non-Euclidean coordinate systems include the *Gaussian* coordinate system and the *Riemannian* coordinate system (Iliev 2006).

4.2.4 The Meaning of Time

On the other hand, one of the main difficulties encountered by any attempt to determine an appropriate space–time coordinate system is the exact *meaning* of time. As St. Augustine famously said,

[4] For place is the origin of things.

> What, then, is time? I know well enough what it is, provided that nobody asks me but if I am asked what it is and try to explain, I am buffled.

As noted earlier, while space conceptions are perceived externally (obtained directly by the agent's senses), time conceptions are experienced internally.[5] Space is three-dimensional, in general, whereas time is one-dimensional. Unlike space, time has no breadth or thickness but only length. The way we measure time is fundamentally different and more involved than the way we measure space. While space can be considered along any direction, time moves in only one direction (i.e., forward). On the other hand, time conceptions can be formed indirectly in terms of the space conceptions. In western thought, time is represented as an infinite geometrical line. Our time words can accurately distinguish between past, present, and future.

Greeks had two different words for time. One word was chronos (*χρόνος*), which means time on the move (time as before and after, time as the future passing through the present and so becoming the past). The other word was kairos (καιρός) and refers to time as an opportune moment, as a moment or occasion, time as qualitative rather than quantitative. Aristotle believed that time can be represented by the image of movement along a line, which may be either a straight line (when the time forms of past, present, and future are concerned), or a circular line (when one needs to indicate measurable time, such as astronomical and physical). In fact, Aristotle's analysis of the time concept was quite remarkable. According to Thorleif Boman (1970: 125), "Aristotle analyses the essence of time – time, that is, which is almost exclusively physical, which is manifest in motion from place to place – he achieves such depth and subtlety that a modern commentator, filled with admiration, can say that his analysis of the essence of time opens a direct path to the four-dimensional algebra to which so much attention is given in connection with the theory of relativity." Lastly, the Hindu concept of time offers a more cosmic perspective: the process of creation moves in cycles and each cycle is marked by four epochs: *Satya Yuga*, *Treta Yuga*, *Dwapar Yuga*, and *Kali Yuga*. Since the creation process is cyclical and never ending, it begins to end and ends to begin; as in Nature, everything goes in circles.

4.2.5 The Space–Time Metric

Building on the conceptual analysis above, the space–time *metric*, $|\Delta \boldsymbol{p}| = |\boldsymbol{p}_i - \boldsymbol{p}_j|$, can be seen as a mathematical conception that defines spatiotemporal distance within the continuum E. *Ipso facto*, for an attribute that occurs in a natural continuum this metric expression depends on two prime factors: a *relative* factor, i.e., the particular coordinate system; and an *absolute* factor, i.e., the nature of the continuum E imposed by physical constraints (such as geometry of space, physical laws, and internal structure of the medium within which a natural attribute takes place).

[5] Kant, e.g., called time an "internal sense."

In summary, the choice of the form of $|\Delta \boldsymbol{p}|$ can generate ways of imagining one's space–time world that can alter one's sense of what is possible and meaningful. Among other things, a metric provides the necessary information to determine the nature of the domain (e.g., whether it is a flat two-dimensional domain or a spherical one). In fact, as scientific theories become more advanced, one discovers that the metric possesses more information than was previously thought. For example, what previously appeared to agents as arbitrary laws of Nature are really consequences of the fact that the continuum E is characterized by a certain kind of geometry (in which case, the natural laws are replaced by concepts and principles of that geometry). In addition, the permissibility of using a mathematical function as a space–time dependence model is not a guaranteed affair but is rather affected by the metric that determines space–time distance in several dimensions.[6] This is a good time to bring to the discussion the fact that many people find it conceptually valid and technically convenient to distinguish between separable and nonseparable space–time metrics.

4.2.6 Separable Metric Structure

This sort of metric is based on the conceptual distinction that justifies the separation of space and time, so that the emerging *separable metric structure* includes a spatial distance $|\boldsymbol{s} - \boldsymbol{s}'| = |\boldsymbol{h}|$ and an independent time lag $|t - t'| = \tau$; in symbolic form,

$$|\Delta \boldsymbol{p}| = (|\boldsymbol{h}|, \tau). \tag{4.3}$$

The spatial distance $|\boldsymbol{h}|$ may have different meanings, depending on the topographic space used. Examples of $|\boldsymbol{h}|$ are given in Table 4.1. The Euclidean distance is considered in a rectangular coordinate system on R^n. The absolute (non-Euclidean) distance may represent, e.g., the length of the shortest path traveled by a particle moving from a point to another, when the particle is constrained by the physics of the situation to move along the sides of a grid. In the case of the spherical distance, the Earth is considered as a sphere with radius r, whereas $\Delta\phi$ and $\Delta\theta$ (in radians) denote the latitude and longitude differences, respectively. A general expression for spatial metrics, Euclidean or non-Euclidean, is as follows

$$|\boldsymbol{h}| = \left(\sum\nolimits_{i,j=1}^{n=1} \varepsilon_{ij}\, h_i\, h_j\right)^{1/2}, \tag{4.4}$$

where ε_{ij} are coefficients that depend on the spatial location. The tensor $\boldsymbol{\varepsilon} = (\varepsilon_{ij})$ is called the metric tensor. In an earlier work (Christakos et al. 2000), it was shown that the rectangular, the polar, the cylindrical, the spherical, the Gaussian, and the Riemannian coordinate systems are all special cases of Eq. (4.4). The interested reader is

[6] We will revisit this important topic in Chapter 5.

Table 4.1 Spatial distances, $|\boldsymbol{h}|$

Euclidean distance: $\left(\sum_{i=1}^{n} h_i^2\right)^{1/2}$
Non-Euclidean distance ($1 \leqslant \mu < 2$): $\left(\sum_{i=1}^{n} \lvert h_i \rvert^{\mu}\right)^{1/\mu}$
Non-Euclidean (*absolute*) distance ($\mu = 1$): $\sum_{i=1}^{n} \lvert h_i \rvert$
Non-Euclidean (*maximum*) distance: $\max\ (\lvert h_i \rvert;\ i = 1, \ldots, n)$
Non-Euclidean (*minimum*) distance: $\min\ (\lvert h_i \rvert;\ i = 1, \ldots, n)$
Spherical (*earth surface*) distance: $r\sqrt{\Delta\phi^2 + (\cos^2\phi)\Delta\theta^2}$

referred to the relevant literature for more details on the matter (e.g., Christakos et al. 2002; and references therein). Note that the spatiotemporal metric and the coordinate system in which the metric is evaluated are independent (an exception is the rectangular coordinate system, the definition of which involves the Euclidean metric).

Metrics can have considerable implications on both the space–time domain E and the attributes that take place within E. Different metrics defined on the same domain may yield different representations of the geometric properties of the domain considered, and the features of the attribute under investigation. Let me clarify the matter with the help of two instructive visual examples, as follows. In the case of spatial domain *isotropy* (R^2), let Θ be the set of points at a distance $r = |\boldsymbol{h}|$ from a reference point O. Fig. 4.1a shows that for the Euclidean distance metric the set Θ is a circle of radius r, whereas for the absolute distance the Θ is a square with sides $\sqrt{2}r$. This example illustrates how the two metrics can lead to different geometric properties of space. Also, in the case of an isotropic attribute feature, the implication is that the values of this feature depend only on the magnitude $|\boldsymbol{h}|$ of the vector distance $\boldsymbol{h}$ and not on its direction. This is the case of the isotropic attribute covariance considered later in this chapter, where the set Θ (Fig.4.1a) also defines an isocovariance contour. The readers are surely aware of several other in situ situations (including the case of *spherical data* often emerging in climate studies) where the standard Euclidean metric used in many commercial software packages (statistical, geostatistical, and GIS) is not physically meaningful. Separable space–time metrics have been used extensively in scientific applications, sometimes for the wrong reason: "Because computations in general spatiotemporal models are often intensive, interest has focused on separable, over time and space, models" (Gryparis et al. 2007: 184), without necessarily checking whether the underlying physical structure justifies the use of the separability assumption.

4.2.7 Composite Metric Structure

Composite metric structures recognize that there are in situ situations in which time may be inseparable from the spatial coordinates. Hence, such metrics require a higher level of physical understanding of space–time, which may involve theoretical and empirical facts about the attribute. The metric is determined by the

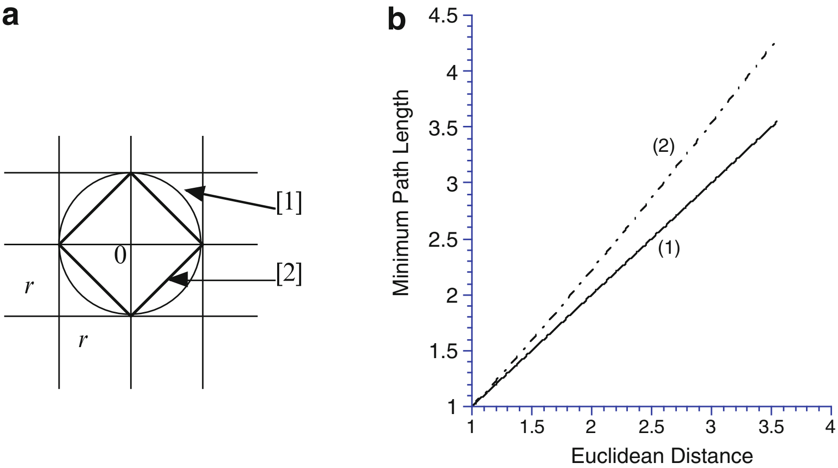

Fig. 4.1 (**a**) Set Θ of points at distance r from 0 when r is [1] the Euclidean distance, and [2] the absolute distance; Θ also defines an isocovariance contour. (**b**) Minimum path length between two points separated by (1) distance r in Euclidean space, and (2) in a space with fractal length dimension $d_o = 1.15$

geometry of space–time, the physical process, and the composite space–time structure it generates. In composite metrics the structure is interconnected by an analytical expression of the form

$$|\Delta \boldsymbol{p}| = \varepsilon(h_1, \ldots, h_n,\ \tau), \tag{4.5}$$

where ε is a function determined by the knowledge available (evidence, topography, physical laws, and scientific model). Concerning knowledge representation, the Euclidean and non-Euclidean geometries display remarkable differences. Euclidean geometry determines the metric that constrains the physics, in which case a single coordinate system implying a specific metric structure covers the entire spatiotemporal continuum. Non-Euclidean geometries distinguish between spatiotemporal metric and coordinate system, thus allowing for choices that may be more suitable for certain real-world problems. A special case of Eq. (4.5) is the space–time generalization of the spatial distance (4.4) that leads to the spatiotemporal *Riemannian* metric (Christakos 2000),

$$|\Delta \boldsymbol{p}| = \left(\sum\nolimits_{\boldsymbol{i,j}=1}^{\boldsymbol{n}} \varepsilon_{\boldsymbol{ij}}\, h_i\, h_j + 2\tau \sum\nolimits_{i=1}^{n} \varepsilon_{0\mathrm{i}}\, h_i + \varepsilon_{00}\tau^2 \right)^{1/2}, \tag{4.6}$$

where the coefficients ε_{ij} $(i,\ j = 1, \ldots, n)$ are functions of spatial location and time period.

Yet, if the meaning of a space–time metric lies in the theoretical knowledge energized in Eqs. (4.3)–(4.6), how is an investigator to secure on objective perspective on physical space–time? In several problems the separate metric structure (4.3) and (4.4) is adequate (Bogaert 1996; Kyriakidis Journel 1999; and references therein). In other situations, however, the more involved composite structure (4.5) and (4.6) may be necessary. Considering the several existing spatiotemporal geometries that are mathematically distinct but a priori and generically equivalent, the metric structure (i.e., function ε) that best describes reality must be determined. Mathematics describes the possible geometric spaces, and empirical knowledge determines which best represents the physical space. Axiomatic geometry is not sufficient for physical applications in space–time, and it is required to establish a relationship between the geometric concepts and the empirical[7] investigation of space–time as a whole.

4.2.8 Fractal Metric Structure

Many attributes that occur in nonuniform spaces with many-scale structural features (e.g., porous media) are better represented by *fractal* rather than Euclidean geometry. In fractal spaces, sometimes it is not possible to formulate explicit metric expressions such as Eqs. (4.5), since some physical laws may not be available in the form of differential equations. Geometric patterns in fractal space–time are statistically self-similar over a range of scales (Feder 1988). Self-similarity implies that fractional (fractal) exponents characterize the scale dependence of geometric properties (e.g., the percolation fractal generated by the random occupation of sites or bonds on a discrete lattice).

Distance measures on a percolation cluster (Stauffer and Aharony 1992), denoted by $\ell(r)$, scale as power laws with the Euclidean (linear) size of the cluster. Power-law functions are called fractals if the scaling exponents are noninteger. Fractals are homogeneous, i.e., they satisfy $\ell(b\,r) = b^{d_o}\ell(r)$, where r is the appropriate Euclidean distance, d_o the fractal exponent for the specific property, and b a scaling factor. In practice, scaling relations such as the above hold within a range of scales bounded by lower and upper cutoffs, thus leading to the formula

$$\ell(r) = \ell(r_{\mathrm{co}})(r/r_{\mathrm{co}})^{d_o}, \tag{4.7}$$

where r_{co} is the lower cutoff for the fractal behavior. The length of the minimum path on percolation fractal scales as $\ell_{\mathrm{min}}(r) \propto r^{d_{\mathrm{min}}}$. Fig. 4.1b, e.g., shows the minimum path length between two points separated by r in Euclidean space and in fractal space with $d_o = 1.15$. The Euclidean path length is a linear function of the distance between two points, for all types of paths (circular arcs or linear segments). The fractal path length increases nonlinearly, since the fractal space is nonuniform and obstacles to motion occur at all scales. Fractal covariances characterizing space–time heterogeneous phenomena can be derived from generalized random fields (Section 5.8).

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[7] The term “empirical” includes different kinds of knowledge (observational data, evidential support etc.).

4.2.9 The Informativeness of Metrics

Earlier in this chapter, we considered the fundamental dilemma, whether space–time can be viewed as a canvas that exists independent of the artist who paints on it, or space–time is akin to parenthood that does not exist until there are parents and children. In theory, this is a deeply philosophical dilemma to which not definite answer has yet been given. On practical grounds, it is obvious that the canvas representation may work well in some real-world cases, whereas the parenthood interpretation may be needed in some others.

As noted earlier, within the space–time domain E, the coordinates are used to locate "events" (rather than just points in space), so time is added as another dimension. This is an important change of view in space–time analysis, since it implies that a space–time coordinate system and its metric are *informative* entities. Indeed, beyond defining location and establishing distance within a spatiotemporal domain E, a metric also contains valuable information about other aspects of the domain E. By means of the metric, e.g., one can realize whether the shape of the domain is flat or curved; or if an attribute feature is isotropic or not. Remarkably, in several studies, this can work the other way around, as well: Physical attributes and the laws governing them may play a central role in the determination of an appropriate metric across space–time. A possible physical scenario is as follows (Christakos et al. 2000): The spatial attribute $X_{\boldsymbol{s}} = X(s_1,\ s_2)$ denotes the hydraulic head, in which case its spatial distribution in a two-dimensional domain is governed by the Laplace equation

$$\nabla^2 X_{\boldsymbol{s}} = 0. \tag{4.8}$$

In the case of radial flow, Eq. (4.8) admits a solution of the form $X_s = X(\sqrt{s_1^2 + s_2^2})$. Hence, the spatial metric suggested by Eq. (4.8) is the Euclidean, $|\boldsymbol{s}| = \sqrt{s_1^2 + s_2^2}$, and so is the physical domain of the phenomenon. In the same work, we also studied the case of two-phase flow in a porous domain. In this case, the governing equations for phases α (= water and oil) are

$$\tfrac{d}{d\ell_\alpha} X_\alpha + \phi(\boldsymbol{e}_\alpha,\ K_\alpha) X_\alpha = 0, \tag{4.9}$$

where X_α is now the magnitude of the pressure gradient in the direction $\boldsymbol{e}_\alpha$ of the α-flow path trajectory, K_α are the intrinsic permeabilities of the phases, and ϕ is a function of $\boldsymbol{e}_\alpha$ and K_α. We then concluded that the solution of Eq. (4.9) should be of the general form $X_\alpha = X_\alpha(|\boldsymbol{s}|)$, where the corresponding metric $|\boldsymbol{s}| = \ell_\alpha$ is the distance along the α-flow path. Therefore, the physical laws (4.7) and (4.8) have led to the determination of two different metrics associated with distinct spatial variations of the attributes under consideration.

In summary, what the above examples offer is yet another demonstration of the fact that the space–time metric establishes a fundamental relationship that refers directly to the four-dimensional reality of the natural environment. In general, the space–time geometry and the natural laws are not independent of each other. Most space–time theorists would probably agree that it is a matter of deep understanding how to combine these two parameters (geometry and laws) in the solution of an in situ problem. In some situations, it may be preferable to preserve a traditional (Euclidean) geometry, whereas in some other situations, the adoption of a non-Euclidean spatiotemporal geometry may be worth considering. Whatever decision is made it ought to be based on the adequate identification of the space–time dynamics internal to the phenomenon and revealed through different means of cognition.

4.3 Dealing with Uncertainty

Humans have been struggling with uncertainty since the very early days of their existence on planet Earth. Uncertainty has always been an extremely inventive and unpredictable feature of human affairs, as regards the expressions and forms in which it chooses to present itself. In this section, I will attempt a critical introduction to the notion of uncertainty from various perspectives (scientific, philosophical, historical, social, and literary) so that an integrated formulation of the notion in quantitative terms can become a real possibility.

4.3.1 Kundera's Paths in the Fog

In his essay, *Paths in the Fog*, Milan Kundera suggests that Man proceeds in the present always in a fog, unsure of what the next moment may bring. The "fog" here is the uncertainty characterizing many aspects of Man's life. Moreover, Kundera notices that Man's present judgment of people of the past fails to appreciate the fact that uncertainty has limited people's actions: "But when he looks back to judge people of the past, he sees no fog on their path" (Kundera 1996). Kundera's message is that, when one judges the actions of others, one should recreate their "fog" (uncertainty) as part of one's creative act of imagination. The "fog" should be taken seriously into consideration, when one attempts to develop a meaningful description and understand real-world phenomena of the past, the present, or the future.

Uncertainty and its consequences occupied peoples' minds since the dawn of civilization. Around sixth century BC, Xenophanes and Parmenides questioned knowledge reliability due to the uncertainty conditions characterizing the epistemological inquiry of erring morals. Plato held that a human being could have only uncertain knowledge of reality through particular objects presented to the senses, whereas certain knowledge was limited to the ideal realm of the "forms" (of which particular objects were but incomplete copies). In *Timaeus* (Τίμαιος) Plato suggested a physics that was "probable" and, hence, uncertain (Hadot 2006). This fundamental insight was put in a rigorous mathematical form by Werner Heisenberg and Erwin Schrodinger among other eminent theoretical scientists of the twentieth century. Interestingly, the only early Chinese scholars who dealt with the matter of uncertainty were the Daoists, although their approach was quite different than that of the ancient Greek thinkers. David Keightley (2002: 119) points out that, "Early Chinese authors and thinkers were certainly aware of the difference between appearance and reality but, unlike a significant number of their early Greek counterparts and – with the possible exception of Chuang Tzu – they did not regard the difference as a significant concern of their narrative of philosophy." Chuang Tzu believed that all forms of reality were relative and uncertain, and that none of these forms was more important than the others. Also, uncertainty appreciation is evident in ancient Hindu texts. Among them, a remarkable passage from the *Hymn of Creation* (Rig-Veda) emphasizes uncertainty in human life, as follows: "Who knows for certain? Who shall here declare it?"[8]

4.3.2 Toward an Anthropology of Uncertainty

It has been said that a metaphor is "a lie that tells the truth." Perhaps, Paulo Coelho's brilliant novel *The Witch of Portobello* provides a useful metaphor of what the actual aim of using the uncertainty concept is (Coelho 2008a). The central question in Coelho's novel is how can a human agent be true to oneself, even if one is uncertain who one really is. Ergo, thinking under conditions of uncertainty should seek the truth about phenomena that, together with the agent, are immersed in an ocean of incomplete records, multiple possibilities, and contradictory evidence.

4.3.2.1 Uncertainty and Human Existence in the Real-World

In the early eighteenth century, Giambattista Vico argued that *Verum et factum convertuntur*.[9] Human truth, Vico believed, is limited to or "convergent with" the things which humans themselves have made. According to this principle, models (mathematical, conceptual, etc.) are clearly human constructions. The same is true for the various kinds of experiments devised by humans. Vico's principle and similar reflections introduced the notion of uncertainty as a result of the obvious yet subtle distinction between the real-world and its human representations (theoretical models and experiments): agents can have absolute control and rational knowledge about the latter, but very rarely about the former. A direct consequence of this distinction is the

[8] The *Rig Veda* is an ancient Indian sacred collection of Vedic Sanskrit hymns. It was composed roughly between 1,700–1,100 BC. The Vedas are the four earliest Hindu texts, and the *Rig Veda* is the oldest and most holy of the four. The word Veda means knowledge or wisdom, and the word Rig means praise in Sanskrit. The Rig Veda is a collection of hymns that sing praise for the gods (or *devas*).

[9] "The true and the made are convertible." This is known as the *verum factum* principle, which implies that truth is verified through creation and invention, and not through mere observation.

warning that we should not assume that whatever is valid about a model or an experiment is necessarily valid about the in situ aspects they represent. To some extent, people study more their own models (i.e., themselves) than they study Nature. Modernism[10] assigned a central role to the notion of *chance*. Modernism is associated with two basic proposals that characterized the mentality of the people of that era: what exists was created by chance, and the evolutionary emergence of what is rational.

Today, all sensible human beings (or at least those with mortgage payments) realize, sooner or later, that they cannot afford ignoring uncertainty and its potentially grave consequences. Indeed, in real-world situations the uncertainty characterizes every aspect of one's knowledge of the past as well as one's predictions of the future. Uncertainty can arise in a number of ways, including the commonly encountered fact where an investigator does not know a priori the outcome of an experiment, the values of a physical attribute across space–time, the decisions of a political establishment, or the future states of a social system. Uncertainty is also associated with our knowledge of the past and may be because records of the past are often incomplete and the evidence inaccurate and even contradictory.

Yet another source of uncertainty is an agent's unawareness of relevant developments in disciplines outside one's expertise. Unable to appreciate this sort of uncertainty, the disciplinary expert also ignores that these developments can exert a serious influence or even question the validity of the results obtained in the expert's own domain. For example, markets that were unwisely allowed to grow in an isolated and "self-regulated" environment led to the development of complex economic tools and highly specialized practices that obtained a life of their own, largely ignoring crucial and highly relevant concepts and criteria of financial risk assessment, with tragic results. In the IPS context, a useful classification is between epistemic uncertainty and ontic (or aleatory) uncertainty. Ontic uncertainty is due to the intrinsic and indeterminate features of the natural system, whereas epistemic uncertainty is a cognitive state that is primarily due to the fallibility and incompleteness of an agent's knowledge. Weather unpredictability is due to the character of chaotic systems (sensitivity to initial conditions, natural variability of the system, etc.). Unpredictability also results from one's limited knowledge of initial states, reliability issues linked to numerical weather prediction models, and so on. In this sense of things, there may exist epistemic uncertainty about ontic uncertainty. IPS encounters ontic uncertainties that are irreducible, epistemic uncertainties that are reducible (conceptually resolvable), as well as mixtures of ontic and epistemic uncertainties. The distinction between the above uncertainty types is useful because epistemic uncertainty is reducible. As we will see in Chapter 7, uncertainty is linked with the concept of information (e.g., information can either generate or reduce uncertainty). Also, following the discussion in Section 3.8.1, epistemic uncertainty may be linked to *ignoramus* (unknown aspects of the world), and certain cases of ontic uncertainty with *ignorabimus* (unknowable

[10] A cultural movement that arose in the late 19th–early 20th centuries and questioned the axioms of the previous age (it emphasized humanism, viewed humans as part of and responsible to Nature, and argued for cultural relativism).

aspects of the world). Last but not least, one may consider positive and negative types of uncertainty, in the sense that uncertainty is not only associated with risk (a potentially negative effect), but also with promoting creativity (a positive effect), see Section 4.3.4.

In general, given the various meanings and forms of uncertainty that an agent encounters in situ, no scientific study can afford not to rigorously account for uncertainty and its implications. Expertise in a specific discipline can influence the perception of uncertainty and its potential consequences. This is fine, as long as it does not misleads one to make unfounded generalizations. It is possible that, while a particular uncertainty concept is appropriate in one area of expertise, its implementation is problematic in another. The contextual essence of uncertainty is something that many practitioners fail to grasp, favoring instead a convenient yet one-dimensional representation of a deeply involved notion in terms of inadequate commonsensical interpretations and so-called “gut feeling” (e.g., Section 2.5.2). In light of the above analysis, it seems that eighteenth century thinkers were more sophisticated than some twenty-first century expert practitioners.

4.3.2.2 Cézanne’s and Godard’s Conceptions of Uncertainty

The importance of uncertainty, in its various forms, has been appreciated not only in science but in art as well. In painting, Paul Cézanne revised realism to include uncertainty in an agent’s perception of reality. In representing (i.e., reproducing by a concept or work of art) objects existing outside the mind, one needs to account the uncertainty generated by the effect of subject–object interaction, thus painting the effect of human perception of reality rather than reality itself. The latter distinction shares some similarity with Giambattista Vico’s distinction between the real-world and its human representation.

In Jean-Luc Godard’s movie *Band of Outsiders*, a miscalculation delays the seemingly perfect plan of two friends to make a big score in life, resulting in a confrontation that has dire consequences. Godard’s masterpiece shows that even a perfect plan is at the mercy of an unexpected event, a dependence that can be expressed in the most dramatic way. In summary, almost every facet of human existence emphasizes, in its own unique way, the importance of an agent been prepared to handle unexpected situations, and consider uncertain problem-solutions with adverse consequences.

4.3.2.3 Uncertainty in Politics and Business

Uncertainty about the facts and their interpretation is an important reason that science has been highly politicized. Taking advantage of uncertainty, more often than not personal preferences or even prejudices are presented as real facts in an effort to gain political power and achieve certain goals. One can find many examples in recent history where governments with the help of the media used real or imaginary uncertainties about major world events to manipulate public opinion (Sections 1.3 and 1.4). Moreover, one can find in the relevant literature and the news media several examples of science projects and policies that failed because they were largely unaware or seriously underestimated in situ uncertainties. Always operating in the gray zone, these examples multiply with increased frequency nowadays, which brings to mind Richard Feynman's famous conclusion in his report about the shuttle Challenger accident: "For a successful technology, reality must take precedence over public relations, for Nature cannot be fooled."

The real-world has its independent existence, i.e., many of its elements exist independent of humans who have an incomplete and uncertain understanding of them. This comment could not be more valid than it is in the finance sector. To illustrate the role of uncertainty in finance, Nassim N. Taleb suggested the metaphor of a "Russian roulette." The revolver, which contains a bullet in one of its six chambers, is put to one's head. Each outcome of pulling the trigger corresponds to one possible realization of a real-life situation. "Reality is far more vicious than Russian roulette. First, it delivers the fatal bullet rather infrequently, like a revolver that would have hundreds, even thousands of chambers instead of six. After a few dozen tries one forgets about the existence of a bullet, under a numbing false sense of security" (Taleb 2005: 26). This is a powerful illustration of the "fooled by uncertainty" problem in politics or in business.

4.3.2.4 Natural and Mental States

It is rather obvious that uncertainty and variability characterize every aspect of life to the point that the possibility of an *anthropology of uncertainty* has been considered (Boholm 2003). Accordingly, uncertainty is viewed as a fundamental experiential realm of human existence associated with incomplete understanding and risk-taking, and as a natural experience within the process of knowledge seeking. Consequently, when an agent considers a mathematical model *M* representing an in situ system *Q* (Section 2.3.2.2), a basic distinction should be made between studying the model *M* representing the system *Q*, and studying the system *Q* itself (the term "studying" may not have the same meaning in the two cases). This distinction makes sense in light of the following arguments concerning a natural state and its representation by a mental state:

a. The *conceptual uncertainty* is a fact of life, i.e., in many cases the model *M* is an incomplete representation of *Q*. Uncertainty associated with an inadequate model structure (conceptualization) may be far detrimental to its predictive ability concerning the real features of *Q*.
b. The *simplification tendency* of problem-solution procedures according to which *M* is assumed to represent a closed system (operates in a controlled environment, there are no extenuating circumstances, its components are established independently, and the laws of symbolic logic apply), whereas the in situ *Q* is an open system (input parameters are incompletely known, uncertain influences and dependencies exist, and simplifying assumptions of varying validity are made).
c. The *transfactuallity hypothesis* presupposes that the same mechanisms of Nature can exist and act in either an open system (associated with *Q*) or a closed system (linked to *M*). This is not the case of many in situ systems and their

representations. When experiments under controlled conditions disclose the properties of particular materials (e.g., certain plastics are good electrical insulators), this knowledge can be applied to make useful instruments like electrical safety devices. Obviously, this application makes sense only when it focuses on those properties of a closed system that remain valid in an open system.[11]

The message of the discussion so far is that, in real-world situations one is hardly ever dealing with the ideal situation plotted in Fig. 4.2a: all inputs are perfectly known, the model *M* is an exact representation of the natural system under consideration, and there are no serious sources of uncertainty involved, in which case a standard solution of model *M* in a strict mathematical (deterministic) sense seems plausible. However, reality is more closely represented by Fig. 4.2b where some or all of the inputs are incompletely known, *M* is not an exact representation of the natural system, and there are considerable sources of uncertainty and other effects. Under these circumstances, a standard solution makes less sense, and questions like the following seem legitimate: Why to choose a solution strictly satisfying *M*, if *M* is not an exact representation of the in situ system, and its inputs are uncertain? Is it possible that a nonstandard solution exists that offers a good fit to the cognitive description of the in situ system incorporating all relevant knowledge sources and associated uncertainties? In a conceptual milieu, answers to such questions have their roots in Aristotle's thought on the coexistence and constructive interaction of uncertainty with causality, which is the subject of the following section.

4.3.3 Uncertainty and Structure in Aristotle's Poetics

An interesting conception of uncertainty is created by the *coexistence* of randomness (chance) and structure (necessity or causality). For many historians of sciences, traces of the idea of coexistence are found in Aristotle's *Poetics* in fourth century BC (Sheynin 1974: 98–100),

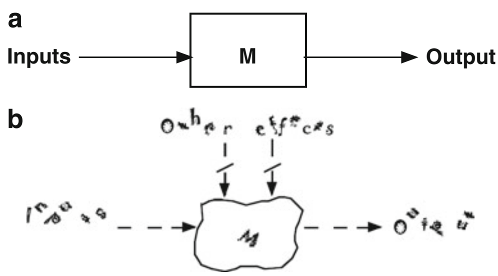

Fig. 4.2 (**a**) An ideal modeling situation, and (**b**) a real-world modeling situation

[11] Which is why investigators are more successful when they study the behavior of systems they have constructed themselves (car, radio, and other devices) than when they study systems created by Nature (e.g., weather, or earthquakes).

> Aristotle was the first to attempt an explanation of chance. Aristotle . . . connects the chance occurrence of sex with natural necessity, i.e., with a definite (optimal) ratio of males and females for any given species . . . this seems to be the first statement connecting chance and necessity.

Otherwise said, Aristotle was the first who demonstrated the semantic contrast between the notions "chance" ($\tau\acute{\upsilon}\chi\eta$) and nature ($\varphi\acute{\upsilon}\sigma\iota\varsigma$). Thomas Aquinas, who was one of the main thirteenth century commentators of Aristotle, refers explicitly to Aristotle's ideas concerning the connection between chance and necessity in his *Summa Theologica*.[12] Remarkably, elements of the concept of coexistence also characterize the philosophy of Immanuel Kant who, opposing Isaac Newton's idea of strict determinism, suggested that random effects coexist with general causes (Sheynin 1974: 135).

A basic IPS feature under conditions of uncertainty is the idea of blending randomness (state of human mind due to incomplete data, multiple possibilities, and contradictory evidence) with structure (linked to the basic space–time pattern of the phenomenon). A simple example offers some quantitative insight about the randomness-structure association:[13] The study system is Q : *Species growth*. A possible representation of Q is R : *Exponential growth of species*. In mathematical terms R is expressed by the model $M : \frac{d}{dt}\chi_{\boldsymbol{p}} = a\chi_{\boldsymbol{p}}$, where the attribute $\chi_{\boldsymbol{p}} = \chi_{\boldsymbol{s},t}$ is the local ($\boldsymbol{s}$) species population at time t with IC $\chi_{\boldsymbol{s},0}$, and a is a coefficient. The structure of the attribute is represented by the form of M, but the $\chi_{\boldsymbol{s},0}$ and a often cannot be calculated with sufficient accuracy. Then, instead of the deterministic solution $\chi_{\boldsymbol{p}}$ of M, an uncertainty-driven solution $X_{\boldsymbol{p}} \sim f_{X_{\boldsymbol{p}}}$ (with $a \sim f_a, X_{\boldsymbol{s},0} \sim f_{X_{\boldsymbol{s},0}}$)[14] is more appropriate. That is, the single-valued $\chi_{\boldsymbol{p}}$ is replaced by the multi-valued $X_{\boldsymbol{p}}$ that accounts for the coexistence of randomness and structure, and offers a more adequate representation of Q. In Section 5.3, this basic idea leads to the development of the random field concept that models rigorously phenomena varying across space–time.

4.3.4 Uncertainty as an Ingredient of Creativity

Referring to the fertile association between uncertainty and human creativity, Ilya Prigogine once said that, "The future is uncertain . . . but such uncertainty lies at the very heart of human creativity." Rapidly changing real-world systems require flexible responses and innovative solutions to increasingly complex and diverse problems. Far from being a barrier to progress, if properly handled, the uncertainty of these systems can be an essential ingredient of creativity and progress. The rigidity of the deterministic mindset is ineffective in such systems. On the contrary, the ambiguities, doubts, and nondeterminability associated with uncertainty can be

[12] *Treatise on Man*, Q.92, Art.**1**: 489.

[13] The terminology of Section 2.3 is used here.

[14] The "f" denotes a probability function (Section 4.4.7) that offers a mathematical expression of randomness.

the fertile ground for breakthrough ideas to grow and new realms of vision to flourish.

Unfortunately, this is not how the established elites view things. In fact, quite the opposite is the case. "The problem in science is that the way you get ahead is by staying within narrow parameters and doing what other people are doing," Dr. Brawley [chief medical officer at the cancer society] said; "no one wants to fund wild new ideas." For example, in cancer research "the problem, Dr. Robert C. Young[15] and others say, is that projects that could make a major difference in cancer prevention and treatment are all too often crowded out because they are too uncertain. In fact, it has become lore among cancer researchers that some game-changing discoveries involved projects deemed too unlikely to succeed and were therefore denied federal grants, forcing researchers to struggle mightily to continue" (Kolata 2009). Lynn G. Gref (2010: 117) reports that the current research funding system "turns the researcher into 'surviving' financially;" and "proposing an enhancement to work that has already been funded and is in a proven interest area of the sponsor is more likely to be a successful bid than an 'out of the box' or 'off the wall' idea."

4.3.4.1 Metternich Vs. Socrates

Let us consider a rather extreme contrast involving a famous politician and an even more famous philosopher of the past. Prince von Metternich was a major figure of late eighteenth to early nineteenth century German-Austrian politics who was absolute certain about his actions and his understanding of the world. He is quoted saying that, "I cannot help telling myself twenty times a day: O Lord, how right I am!" (Metternich 2004). On the opposite side, Socrates famous doctrine was that, *Ev οιδα, ότι ουδέν οιδα*, i.e., "One thing I know for sure, that I know nothing with certainty." Generally, epistemic uncertainty expresses a sense of Socratic ignorance about one's knowledge, which can be a healthy state of mind. This state frees human agents from being enslaved by established views or vested interests (as in Metternich's case), and allows them to be really creative. Doubt enriches truth, whereas the feelings of awe, veneration, and wonder inspired by the ineradicable uncertainty of knowledge of the world can turn out to be powerful constructive forces. In this world, and probably in many others, often it is certainty rather than uncertainty that is a barrier to progress. If investigators were certain of the future (so-called determinism), there could be no moral compulsion to do anything. On the contrary, since everything is uncertain, the future is open to possibility and creativity. These facts are not understood by many sponsors who, as we saw above, for agenda-driven reasons insist on certainty in research. This agenda produces banality on a regular basis but at very high cost.

[15] Chancellor at Fox Chase Cancer Center in Philadelphia, and chairman of the Board of Scientific Advisors.

In sum, uncertainty can be a major source of stimulation for human creativity. It provides the required space for all sorts of inventions that defeat the trivial habit. A creative agent meets uncertainty with innovation, and it is the same uncertainty that creates a plethora of opportunities for the prepared mind. In some cases, successful research involves moving beyond established views about the problem of interest. Then, the creativity required for this purpose implies investigating situations beyond what is known, which brings with it inherent uncertainty due to the agent's exposure to the new and mysterious. The mysterious aspect of the uncertainty–creativity association can be a powerful motivation for some people. One of them was Einstein who once wrote: "The most beautiful experience we can have is the mysterious. It is the fundamental emotion that stands at the cradle of true art and true science."

4.3.4.2 How Much Creativity Is Safe? The Case of Hypassus

Tolerance for uncertainty is often a prime prerequisite for a creative IPS approach. Human instincts that give rise to uncertainty are worth preserving, even if they are the source of uncomfortness and phobias. There is always a price to be paid by any attempt that disturbs the status quo, by linking good life with a world in vivo and not in vitro or by viewing research and the search for truth as sources of meaning and purpose in human inquiry and not the means for satisfying materialistic interests (financial gains, consumption needs, promoting careerism, etc.).

A word of warning to the particularly creative among the readers: Established elites do not find it easy to cope with the uncomfortness caused by creativity, and in some cases, they react intensely or even violently. Legendary is the case of uncomfortness and uncertainty that the creative thinking of *Hypassus*[16] caused to the ruling elite of his time, to the point that Hypassus was thrown to his death into the sea. Weird, indeed, the things some people get murderous about. From the stochastic reasoning perspective (Section 1.2.3), a quantitative representation of uncertainty involves, in a way or another, the notion of *probability*, which is the focus of the following section.

4.4 Probability and Its Interpretations

I will start with a brief account of the history of the probability concept and its potential roots. It is remarkable that after so many centuries, the definition and especially the interpretation of probability remain controversial.

[16] That is, his discovery of irrational numbers.

4.4.1 The History of a Concept

The concept of probability has a very long and fascinating history. As early as the fifth century BC, Socrates held that (Sambursky 1956: 36):

> In law-courts men care nothing about truth, but only about conviction, and this is based on probability.

About the same time, Hippocrates, the "Father of Medicine," used to conclude his case histories with commentaries of the type (Sheynin 1974: 117):

> It is probable that the death . . . is to be attributed to . . .

In the fourth century BC, one can find several references to probability in Aristotle's works, *Rhetoric* and *Poetics* (Aristotle 1954). For example, in *Rhetoric*, 1357^a, 34:

> A probability is a thing that usually happens; not, however, as some definitions would suggest, anything whatever that usually happens, but only if it belongs to the class of the 'contingent' or 'variable' . . .

This is regarded by many probability theorists as the first attempt at an analysis of the word (e.g., von Wright 1960: 167). In a similar vein (*Poetics*, 1451^a, 38):

> To describe, not the thing that has happened, but a kind of thing that might happen, i.e., what is possible as being *probable*.

As a matter of fact, Werner Heisenberg maintained that, "The concept of the possibility or 'tendency' for an event to occur plays a decisive role in Aristotle's philosophy. In modern quantum theory, this concept takes on a new form: it is formulated as probability and subjected to laws of nature." Several centuries after Aristotle, Pierre Simon Marquis de Laplace famously uttered:

> The most important questions of life . . . are indeed for the most part only problems of probability.

Accordingly, the present section is concerned with the interpretive fix on probability using the technical presentation of basic ideas combined with illustrative metaphors. Nevertheless, it may be advisable to exert some caution in expressing one's thoughts about the notion of probability in a way that challenges orthodoxy. When one attempts such a thing in a meeting of British statisticians, e.g., one may risk being sent to the Tower of London for breach of the code of professional conduct. Drawing on the conceptual framework introduced earlier, uncertainty may be associated with the agent's insufficient data, inadequate models, and limited means. For example, the uncertainty of medical evidence does not obey any general rule, and there is no algorithm to guide the agent what one should do when one does not know what to do. In any case, it is important that an agent appreciates uncertainty and knows when and how to cope rationally with it in terms of probability, since an adequately conceived concept of probability plays a vital role in everyday life and in scientific thinking alike.

4.4.2 Abstraction and Interpretation

An abstract concept is distinct from its interpretation that connects probability to its empirical properties. As it turns out, the probability concept is relatively easy to define mathematically (see, e.g., Kolmogorov's axiomatic definition of probability below). However, the same is not valid for its interpretation, which turns out to be a much more complex affair. In its everyday use, the so-called common sense[17] probability expresses the likelihood that a specified event will occur, a hypothesis will turn out to be true, and the like. In scientific investigations, probability may refer to any entity (event, proposition, phenomenon, or attribute). As a consequence, probability may assume a variety of meanings, including physical, statistical, sociological, and psychological (see also, Fig. 4.3 later). At this point, I will focus on the probabilistic reasoning of a rational agent and its scientific use. But, on occasion, I will consider noticeable connections between science-based and commonsensical probabilistic reasoning.

4.4.3 Kolmogorov's Formal Approach and Its Interpretive Incompleteness

According to standard terminology, let χ_{p_i} denote a possibility (realization) associated with the attribute X_p. The χ_{p_i} is member of a space V that includes all possibilities concerning X_p. We intentionally assumed a wide range of possibilities

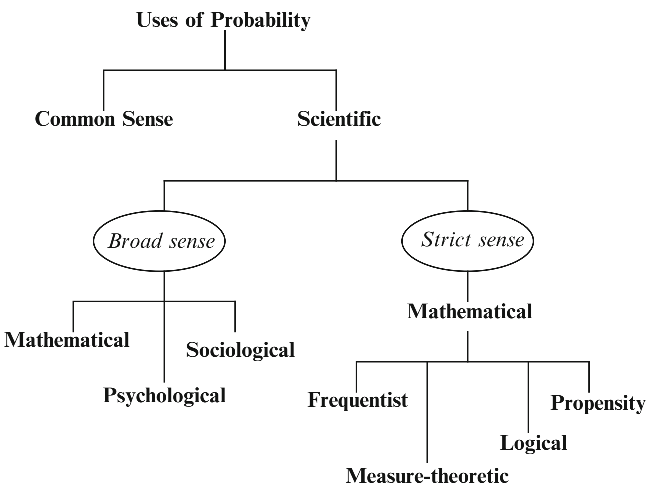

Fig. 4.3 Possible classification of probability uses

[17] The reader may recall that the various features of "common sense" were examined in Section 3.1.2.

above, for reasons that will become clear later. For illustration, let us consider the following examples linked to different real-world phenomena: Experiment $X_p =$ tossing a die, $\chi_p = 3$, and $V = 1, 2, \ldots, 6$. Attribute $X_p =$ temperature, $\chi_p = 75.9^\circ\ F$, and $V =$ all physically possible temperature values. Phenomenon $X_p =$ social status of Monica, $\chi_p =$ *Monica is rich*, and $V =$ all logically possible propositions concerning X_p. When it refers to an experiment or an attribute, the χ_p may assume discrete or continuous values. Tossing a die yields discrete outcomes, whereas the mass and temperature values are continuous. In some cases, all members of the space V are known (e.g., the possible outcomes of tossing a die, or the possible values of physical attribute); whereas in some other cases, not all members of V are known (e.g., a complete enumeration of future diseases is not possible, since nobody knows what the future will bring). To present a rigorous exposition of stochastic reasoning in Chapters 4–6, it is necessary that, in this chapter, we critically scrutinize and carefully define some basic notions of probability theory.

4.4.3.1 Kolmogorov's Axioms

Formally, probability is any quantity that satisfies a set of axioms introduced by the great mathematician Andrey N. Kolmogorov. This formalization (Kolmogorov 1933), which is widely accepted among theorists, is known as the *measure-theoretic* probability and has been the standard mathematical foundation of probability theory since the 1930s. Below we provide a brief presentation of the main axioms introduced by Kolmogorov. To each χ_{p_i} in V one assigns a function $P[\chi_{p_i}]$ such that:[18]

$$P[\chi_{p_i}] \geqslant 0 \tag{4.10}$$

for all $\chi_{p_i} \in V$ (*Axiom* 1);

$$P[V] = 1 \tag{4.11}$$

(*Axiom* 2); and

$$P[\chi_{p_i} \vee \chi_{p_j}] = P[\chi_{p_i}] + P[\chi_{p_j}] \tag{4.12}$$

for all pairwise disjoint (mutually exclusive) $\chi_{p_i}, \chi_{p_j} \in V$: $\chi_{p_i} \wedge \chi_{p_j} = \emptyset$ when $i \neq j$ (*Axiom* 3). The symbol "$\emptyset$" represents the empty set and the symbols "$\wedge$" and "$\vee$" denote conjunction and disjunction, respectively (Section 5.2.1.2). It should be

[18] In the literature, small lettering is often used to denote the probability of a specific realization χ_p of the random field X_p and large lettering (P) to denote the probability of X_p, assuming various values within V. For simplicity, this book uses P to denote both cases.

stressed that the spaces *V* are not necessarily objective properties of the attribute to which the investigator assigns a probability. Rather, they are conceived by the human mind, though not without reference to physical knowledge. According to Epibraimatics it should be useful to study the cognitive processes that generate sets of realizations (possibilities) in the investigator's mind.

4.4.3.2 Interpretive Incompleteness: Connecting Theory with Practice

In the above measure-theoretic scheme, the probabilistic laws governing possibilities (realizations) are also known. For example, there is no quantitative ambiguity in that the probability of the possibility $\chi_{\boldsymbol{p}_i}$ is $P[\chi_{\boldsymbol{p}_i}]$. However, the axioms do not specify how the probabilities should be assigned in the real-world. The interpretive *incompleteness* of Kolmogorov's formulation seems to be an advantage, since it allows the approach to be very general, not restricting its implementation to a few particular situations. In practice, however, interpretive considerations are often a significant matter that must be carefully taken into account. The Epibraimatics perspective requires that theory be connected to practice, often through suitable approximations. This connection may have a number of implications, some of which are discussed next.

A probability statement makes sense only when there is an adequate understanding of the physical situation it refers to. Surely, there exist several levels of understanding, some of which are more incomplete and uncertain than others. Accordingly, the value of a probability statement is closely related to this level of understanding. Which is why an expert toxicologist is in a better position to make meaningful probability statements about poisoning problems than an expert hydrologist. In the same spirit, a major issue in Epibraimatics is how one can connect the theoretical concept of probability with empirical reality (Keynes 1921; De Finetti 1937; Hacking 1975). In other words, how can a rational agent measure probability? Previous sections (e.g., Section 1.7) have emphasized the critical role of the measurement process and the importance of associating its numerical outcomes with physically observable entities. Thus, we have a voltmeter to physically measure electrical potentials, a thermometer to physically measure temperature, etc. But we do not seem to have a *probameter* to physically measure probability,[19] and as a result, it is not always obvious what the physical meaning of a numerical probability value is. Yet another matter of concern in Epibraimatics is the *inexistence* paradox. As was noted earlier, in some cases, not all members of *V* are known a priori. This can raise some issues concerning the application of Kolmogorov's axioms. How can one assign, e.g., a value to an a priori inexistent possibility?

[19] *Inter alia*, this is due to the conception of probability as something not existing outside ourselves.

4.4.4 Physical, Epistemic, Subjective, and Quantum Probabilities

A way out of this rather uncomfortable situation could be to search for an interpretation of probability that assigns evidential referents to mathematical entities, thus establishing a relationship between the real-world in which probabilities are used and their formal description. This possible plan of action has already been mentioned above. In this search, one would distinguish between the following probability interpretations.

4.4.4.1 Physical Probability

Physical probability (PP) is considered as a real feature of the world. The PP has an ontic character, whether or not we ever conceive of or know of it (due to its ontic character per se, the PP is sometimes called *mathematical probability, MP*). As such, the PP is neither relative to evidence nor a mere matter of opinion, with no opinion any better than any other. The chance of radium atoms decaying within intervals of future time, e.g., is a PP because it is a feature of the physical world.

Also, the *frequentist* or *aleatory* probability, championed by Richard von Mises (1931),[20] may be seen as a PP: the probability of an outcome χ concerning the entity of concern is the limit of its relative frequency in a series of independent data (e.g., measurements or observations) when the series becomes infinite long, viz.

$$P[\chi] = n_{\chi} N^{-1}, \tag{4.13}$$

where N is the number of data in the series and n_{χ} is the number of times the outcome χ turned out. Eq. (4.13) has been typically associated with tossing a fair coin. Some historical coin tossing experiments include the following:

Georges Buffon's: $N = 4,040$, $n_{heads} = 2,058$ and $P[heads] = 0.5049$.

Karl Pearson's (first case): $N = 12,000$, $n_{heads} = 6,019$ and $P[heads] = 0.5016$.

Karl Pearson's (second case): $N = 24,000$, $n_{heads} = 12,012$ and $P[heads] = 0.5005$.

Surely, one must admire the patience and time availability of these dedicated men. Nevertheless, some obvious issues emerge concerning the meaningfulness of Eq. (4.13): *circularity*, i.e., independent data are assumed in order to define probability, but independency itself is defined in terms of probability; and *subjectivity*, i.e., the judgment of independence may be subjective. Moreover, Thomas A. Brody (1994) noticed that the frequentist interpretation refers directly to the entities (events, processes, variables, etc.) under consideration rather than to mental representations of them (which is the case of epistemic

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[20] The readers may find it interesting that according to Georg Henrik von Wright (1960: 167),

> Aristotle might be called the initiator of the so-called frequency view which, roughly speaking, sees the meaning of an event's probability in the relative frequency of its occurrence.

probability, see below). He then concluded that by identifying probability with the limit of the relative frequency (4.13), the frequentist approach imposes a number of requirements that often make its implementation in practice very difficult or even impossible (e.g., only trivial events can be considered due to the lack of infinite data sets). Last but not least, according to Karl Popper, the frequentist probability (4.13) cannot be falsified or even verified. In his own words (Popper 1968: 183): "Probability estimates are not falsifiable. Neither, are they, of course, verifiable and this for the same reasons as hold for any other hypotheses, seeing that no experiment result however numerous and favorable, can ever finally establish that the relative frequency of 'heads' is $\frac{1}{2}$ and will always be $\frac{1}{2}$." And the debate goes on.

Following his criticism of the frequentist account of probability, Popper (1957) came up with the so-called *propensity* account of probability.[21] Like the frequency interpretation, Popper's interpretation locates probability "in the world" rather than in mental constructs, but he defines probability as a propensity (tendency or disposition) of the physical situation or the experimental arrangement (kept constant during the experiment) to turn out a specific outcome or to yield a long run relative frequency of such an outcome rather than a tendency of the object under study or the frequency of the outcome itself in a sequence of experiments. For example, the meaning of the statement "a coin has probability $\frac{1}{2}$ of landing heads when tossed" is that a repeatable tossing arrangement has a propensity to produce a sequence of outcomes in which the limiting relative frequency of heads is $\frac{1}{2}$. Some critics argue, however, that if the run of relevant events is potentially infinity, one may have to assume that "probably" the propensity exists or that it is rational to act on it because "probably" it will continue. But the term "probably" is not substantiated, and the propensity interpretation can be subject to many of the objections against the frequentist interpretation.

4.4.4.2 Epistemic Probability

Epistemic probability (*EP*) is not necessarily a real feature of the world in the PP sense. Instead, it is a mental construction that measures how much the available knowledge confirms or disconfirms the agent's hypotheses about the world. According to Laplace, the EP interpretation is "relative in part to [our] ignorance, in part to [our] knowledge" (Howson and Urbach 1993: 22). Another proponent of EP was the legendary polymath Henri Poincaré who said that, "chance is only the measure of our ignorance." In more recent times, EP has been the subject of an emergence of probability study by Ian Hacking (1975).

Its proponents are quick to point out that EP is not merely a matter of opinion. Whether, and to what extend, evidence counts for or against a hypothesis or a theory

[21] Although some authors attribute the original idea to Poisson (early nineteenth century), and C.S. Pierce (late nineteenth–early twentieth century).

would be seen as an objective affair. The probability that the big bang occurred, e.g., is an EP that measures the extent to which the astronomical and physical knowledge currently available confirms the big bang theory (as opposed, say, to its steady-state rival theory). From the EP standpoint, probability should denote what a rational agent actually knows about the phenomenon rather than what one believes to be the case (see discussion of knowledge vs. belief in Section 1.1.3.2). In this sense, the *logical* probability interpretation, which involves logical relations between entities and expresses degrees of logical consequence or (partial) entailment, may be viewed as belonging to the EP camp.

Let us consider a simple example that may help the readers understand one of the differences between EP (describing one's state of incomplete knowledge about a natural system) and PP (reflecting certain objective aspects of the system). A human population has m members that possess a specific gene G that makes them susceptible to a deadly disease, and $n - m$ members do not have G. If members are selected at random for testing and χ_1 denotes that a G member was selected on the first draw, the uncertainty about χ_1 is expressed by the probability $P_{KB}[\chi_1] = \frac{m}{n}$. If one knows that a G member was selected at the first draw, the uncertainty of the second draw is represented by the conditional probability $P_{KB}[\chi_2|\chi_1] = \frac{P_{KB}[\chi_1 \wedge \chi_2]}{P_{KB}[\chi_1]} = \frac{m-1}{n-1}$, which expresses a sort of a causal influence of χ_1 on χ_2. Suppose now that we are told that a G member was selected on the second draw. Then, given that the second draw cannot have a physical influence on the first, a physical (ontic) interpretation of the situation would require that $P_{KB}[\chi_1|\chi_2] = P_{KB}[\chi_1]$. On the other hand, although χ_2 cannot affect χ_1 in a physical sense, an epistemic interpretation of the situation implies that knowledge of χ_2 affects our inferences about χ_1. Hence, the uncertainty about χ_1 should be expressed by $P_{KB}[\chi_1|\chi_2] = \frac{m-1}{n-1}$. That is, whether uncertainty is viewed from an epistemic or a physical standpoint can affect the outcome of the analysis. Of course, this thesis begs the question: when should an EP vs. a PP interpretation be used? The answer to this question may depend on the nature of the data available, the role of the observer, and the cognitive accessibility of future events (which are, otherwise, physically and observationally inaccessible).

4.4.4.3 Subjective Probability

"A likely impossibility is always preferable to an unconvincing possibility" wrote Aristotle (*De Poetica* 1460a, 25; see, also, Aristotle 1794), thus introducing a primitive notion of subjective probability (SP) in the fourth century BC. Unlike EP, SP is not an objective affair but rather measures how strongly an agent (or a group of agents) believes a proposition, statement, hypothesis, theory, etc. As such, SP is a feature of the agent whose credence it is, rather than a feature of what the credence is about. One's low credence that the horse named Astrahan will win the Kentucky Derby, e.g., may be a mere matter of my opinion, an SP that needs not be justified by any corresponding physical or epistemic evidence. Accordingly, subjective in the personal belief sense should not be confused with epistemic. An assertion is subjectively probable if the agent believes so, whereas an assertion is epistemically probable when there is sound evidence that supports this assertion although the evidence is not logically conclusive. For example, it does not make much sense to talk about the probability of the assertion "all unmarried men are bachelors". On the other hand, there is good evidence for the assertion "Darwin's theory is correct" although this evidence is not logically conclusive.

As shown in Section 2.2.2, the subjective interpretation of probability theory is an influential case of Parmenidean apology. In modern times, the subjective interpretation was championed by Bruno De Finetti who introduced the "operational subjective" notion of probability (De Finetti 1937). Famous is De Finetti's provocative statement, "Probability does not exist," which implies that probability does not exist in an objective sense but only subjectively within the minds of individual agents. In which case, some critics argue, what an agent believes does not necessarily have anything to do with the in situ situation, although it is liable to quantification so that it satisfies Kolmogorov's axioms. Whatever the SP case may be, what must be avoided is the *unconstrained* subjectivism state, i.e., a subjective interpretation of in situ probabilities that places no constraints on the agents: there is no limit to what agents might assign, and hence anything goes. As such, unconstrained subjectivism would be seen as a radical postmodern approach to probability.

4.4.4.4 Quantum Probability

In modern physics, it is a matter of debate whether *quantum probability* can be seen as a PP or an EP. The laws of combining probabilities in quantum theory are different than the classical ones. Let $P[\chi_{p_i}] = \beta_i$ $(i = 1,\ 2)$ denote the probabilities of the independent events χ_{p_i}. In the everyday world, the probabilities are associated with the agent's epistemic condition so that

$$P[\chi_{p_i} \vee \ \chi_{p_j}] = P[\chi_{p_i}] + P[\chi_{p_j}] = \beta_i + \beta_j. \tag{4.14}$$

In the quantum world, on the other hand, one sums up the probability amplitudes rather than the probabilities themselves (in quantum theory, probabilities are calculated from amplitudes using a squaring process; Dirac 1947). That is, if $|\psi_i|$ $(i = 1,\ 2)$ are the quantum probability amplitudes of χ_{p_i}, then $P[\chi_{p_i}] = \beta_i = |\psi_i|^2$ are the corresponding probabilities, which implies that

$$\begin{aligned} P[\chi_{p_i} \vee \ \chi_{p_j}] &= (|\psi_i| + |\psi_j|)^2 = |\psi_i|^2 + |\psi_j|^2 + 2|\psi_i||\psi_j| \\ &= \beta_i + \beta_j + 2(\beta_i \beta_j)^{\frac{1}{2}}. \end{aligned} \tag{4.15}$$

Hence, quantum probabilities of independent events combine in an apparently elusive and nonepistemic way. In which case, a basic question arises (Polkinghorne 2002: 42): "would it, nevertheless, be possible to understand quantum probabilities as also having their origin in the physicist's ignorance of all the detail of what is going on, so that the underlying basic probabilities, corresponding to inaccessible but completely detailed knowledge of what was the case, would still sum up classically?"

Let us carry the quantum probability formulation a little further. The operator $P_\psi[\cdot]$ is introduced so that

$$\begin{aligned} P_\psi[g(\chi_{\boldsymbol{p}_i})] &= \int d\chi_{\boldsymbol{p}_i}\, \psi(\chi_{\boldsymbol{p}_i})\, \psi(\chi_{\boldsymbol{p}_j})\, g(\chi_{\boldsymbol{p}_i}) = \psi(\chi_{\boldsymbol{p}_j}) \int d\chi_{\boldsymbol{p}_i}\, \psi(\chi_{\boldsymbol{p}_i})\, g(\chi_{\boldsymbol{p}_i}) \\ &= k_\lambda\, \psi(\chi_{\boldsymbol{p}_j}), \end{aligned} \tag{4.16}$$

where k_λ is a numerical coefficient, and g is a function of the attribute values. The associated eigenvalue equation is $P_\psi[g_\lambda(\chi_{\boldsymbol{p}_i})] = k_\lambda\, g_\lambda(\chi_{\boldsymbol{p}_i})$, which has the solutions $k_1 = 1$ (if $g_1 = \psi$) and $k_\lambda = 0$ (if $g_\lambda \perp \psi$). In other words, the function ψ in Eq. (4.16) is an eigenfunction of the operator P_ψ with eigenvalue unity. The above arrangement suggests an interesting procedure to determine the probability as soon as ψ becomes available from the physical law. The matter will be revisited in Section 5.5.3 in a stochastic reasoning setting.

4.4.5 In Search of the Ultimate Interpretation

It has been said that the art of life consists in knowing how to recognize important life scenarios, and assess the probabilities of their unfolding. But what is the meaning of probability, after all? As it should have become clear by now, the interpretation of a given probability value is by no means a straightforward affair. Instead, depending on the real-world problem under consideration, it can turn out to be a rather tricky and treacherous business with serious consequences in the IPS setting. Surely, one may introduce a set of basic requirements to be satisfied by a probability interpretation attached to a natural attribute, such as: (i) The interpretation should yield meaningful statements when linked to mathematical relations of the probability calculus; (ii) it should generate probability values within the interval [0, 1] and not be limited to a few extreme ones (say, 0 and 1); (iii) it should establish a sound link between the formal probability notion and the in situ properties of the attribute (physical, biological, social, and psychological); (iv) this link should introduce a way to calculate the probabilities in a meaningful and efficient manner; and (v) if natural laws are available, the probability interpretation should be consistent with these laws (Section 5.5.3).

Undoubtedly, probability has a large number of useful applications (the largest part of scientific theories about reality is based on probability concepts). To many scientists, the Requirement (iii) above implies that there may exist at least as many probability uses as there are disciplines (although some disciplinary uses may be linked with the three major interpretations, PP, EP, and SP). The matter is addressed in due detail in the literature, from which we borrow the classification of probability uses in everyday life and the sciences shown in Fig. 4.3 (Christakos 1992). A classification is often a matter of convenience, so other probability classifications may be added to those depicted in Fig. 4.3. Let us consider a few examples. The readers may recall that the frequentist interpretation of probability, Eq. (4.13), is meaningful if the number of all possible events is finite and all events are equiprobable. Hence the frequentist interpretation of probability may be inadmissible in real-world cases in which the events are not equiprobable[22] or are unrepeatable.[23] Also, given a circle, one seeks to find the probability, say p, that a chord chosen at random is longer than the side of an inscribed equilateral triangle. The problem is known as *Bertrand's paradox* (Clarke 2002) and it turns out that the solution hinges on the meaning of the statement "a chord is chosen at random." That is, once the method of random selection is specified, the problem has a well-defined solution. There is no unique selection method, so there cannot be a unique solution. The three solutions presented by Bertrand (i.e., $p = \frac{1}{4}, \frac{1}{3}$, or $\frac{1}{2}$) correspond to different random selection methods, and in the absence of further information, there seem to be no reason to prefer one over another.

Most thinkers agree that there is no ultimate interpretation of probability. As is often the case in life, interpretation simply depends on the circumstances: the PP interpretation may be appropriate in one real-world application, the EP interpretation in another application, and a combination of the EP and SP interpretations in yet another application, and so on. In other words, the different probability interpretations may be partially overlapping or complementary, in which case a suitable combination of the interpretations would be considered. By seeking the best combination possible, one is liable to upset everyone (statisticians who neglect probability's links with physical laws of change, positivists who focus on purely logical assessments of probability, empiricists who rely on the doctrine "let the data talk," etc.). Again, this is the fate shared by those who, not recognizing themselves in any of the "institutionalized" solutions to a problem, seek to synthesize the best elements deriving from the various proposals and end up drawing the wrath of all. Nevertheless, what makes such a quest so inviting is precisely this attempt to find a balance between divergent or even opposing theories, to draw out and combine that which is plausible in each.

[22] As noted earlier, this requirement is logically circular, since a notion of "equiprobability" is defined prior to that of "probability."

[23] This is also known as the "single-case problem."

4.4.6 The Role of Metalanguage

A central message of Fig. 4.3 is that, beyond its elegant mathematics and wide applicability in real-world problems, probability is also a fascinating multidisciplinary subject that involves mathematical, philosophical, psychological, linguistic, etc., notions and arguments. It is not difficult to realize that the probability reference distinction introduces certain questions, such as: Does a probability refer to a proposition or to the agent's assertion about the proposition? Does the probability refer to the actual system Q or to the mental representation R of the system Q? This sort of distinctions are also related to the linguistic matters discussed in Section 3.7, in the sense that the probability of a proposition is associated with the language that refers to the proposition itself, whereas the agent's assertion concerning the probability of a proposition may belong to the metalanguage that refers to the specific assertion about the proposition (the readers were introduced into this important distinction in Section 1.2.3.4). For illustration purposes, consider a weather prediction situation represented by the proposition $A = rains\ \ tomorrow$. Metalanguage considerations indicate a possible yet subtle distinction between $P[A\ occurs]$ and $P[Agent's\ assertion\ that\ A\ occurs]$; i.e., between A that has a certain probability of occurrence, and the probability of an agent's assertion about A's occurrence. In the second case, the term "probability" is used by the agent to talk about the proposition A, and as such, it is part of the metalanguage. As we saw in Section 1.2.3.4, the probability of an agent's assertion that A occurs can be written in an equivalent yet more concise way that reflects agent's epistemic situation,

$$P_{KB}[A] = P[Agent's\ assertion\ that\ A\ occurs\ in\ light\ of\ KB], \tag{4.17}$$

where KB denotes the knowledge base available to the agent on the basis of which the agent asserts that A occurs. Other relevant issues may emerge, as well. For example, should a probability refer to today's actual (yet quite complex or not completely known) physical conditions Q predicting tomorrow's weather, or to a representation R (say, a computational weather model) of Q? The probabilities associated with these two situations can be quite different from each other. Another issue is whether the magnitude of a probability can be non-numerical (described as high, moderate or low probability; greater or less etc.). Johannes von Kries (1886) was probably the first to consider non-numerical probabilities, followed by John Maynard Keynes (1921) who distinguished between non-numerical probabilities vs. unknown numerical ones. Although their conception and metalanguage are rather controversial, non-numerical probabilities have been used in medical sciences and elsewhere (e.g., Gramling et al. 2004). For example, in medicine a probability is often conceived as a logical relation based on analogy. By drawing analogies between present and past symptoms, a physician asserts that a certain disease is more probable than another one, although the physician may not assign a numerical value to this probability. A carefully designed IPS approach would include a metalanguage that considers non-numerical probabilities, assuming that they are consistent with the other study components (KB, logical assessments etc.), and one does not sum apples to oranges, so to speak.

The readers may recall two important special cases of probability theory: in probabilistic terms, *mutual exclusiveness* and *independency* imply that, respectively,

$$P_{KB}[\mathrm{V}_{i=1}^{m} \chi_{\boldsymbol{p}_i}] = \sum\nolimits_{i=1}^{m} P_{KB}[\chi_{\boldsymbol{p}_i}], \tag{4.18}$$

and

$$P_{KB}[\Lambda_{i=1}^{m} \chi_{\boldsymbol{p}_i}] = \prod\nolimits_{i=1}^{m} P_{KB}[\chi_{\boldsymbol{p}_i}], \tag{4.19}$$

where $\Lambda_{i=1}^{m} \chi_{\boldsymbol{p}_i} = \chi_{\boldsymbol{p}_1} \wedge \cdots \wedge \chi_{\boldsymbol{p}_m}$ and $\mathrm{V}_{i=1}^{m} \chi_{\boldsymbol{p}_i} = \chi_{\boldsymbol{p}_1} \vee \cdots \vee \chi_{\boldsymbol{p}_m}$. In Eq. (4.18), the probability of the agent's assertion that the disjunction of the possibilities $\chi_{\boldsymbol{p}_i}$ $(i = 1, \ldots, m)$ will occur is equal to the summation of the probabilities of the individual assertions; whereas in Eq. (4.19) the probability of the assertion that the conjunction of the possibilities will occur is equal to the product of the probabilities of the individual assertions. These and similar formulas play a key role in many stochastic reasoning developments (Chapters 5 and 6).

4.4.7 *Probabilities of Discrete-Valued and Continuous-Valued Attributes*

In the early sixth century, Boethius' insight foreshadowed the existence of a probability law (or function) that governs the chance entities by stating that,

> Chance too, which seems to rush along with slack veins, is bridled and governed by law.

At first glance, using the notions "chance" and "law" in the same sentence seems a contradiction in terms. A more careful look, though, would convince the readers that this sort of apparent contradiction is not uncommon in scientific practice. As a matter of fact, a key idea of uncertainty modeling is that deterministic probability laws (or functions), P_{KB}, govern the chances of nondeterministic (random) attributes. The P_{KB} functions are important in stochastic reasoning calculations, since they assign valid probability values to the realizations of an attribute.

As noted earlier, a realization $\chi_{\boldsymbol{p}} \in V$ associated with an attribute $X_{\boldsymbol{p}}$ distributed across space–time (say, a physical process, a health indicator, or an economic variable) may assume *discrete* values – values that are clearly distinct from each other – in which case one talks of a discretely valued attribute (e.g., the number of deaths during the time-course of an epidemic, the number of children in a low-income family, and the number of defective commercial items in each box). Or it may assume *continuous* values (i.e., one value of the attribute flows into the next, and between any two values there is an infinite number of other possible values), in which case one talks of a continuously valued attribute. In the case of an attribute $X_{\boldsymbol{p}}$ with a countable number of discrete values, one can define the probability function,

$$P_{KB}[\chi_{\boldsymbol{p}}] = P_{KB}[X_{\boldsymbol{p}} = \chi_{\boldsymbol{p}}] = \beta_{\boldsymbol{p}}, \tag{4.20}$$

which measures the degree of expectation $\beta_{\boldsymbol{p}} \in [0,\ 1]$ that $X_{\boldsymbol{p}} = \chi_{\boldsymbol{p}}$, given the agent's epistemic condition. As before, the subscript KB denotes the knowledge base used to construct the probability model. Naturally, the construction of P_{KB} on the basis of KB involves a critical thinking process with cognitive and psychological characteristics (Fig. 4.3), in which case one should make sure that the appropriate P_{KB} interpretation is used. Some noticeable formal properties of the probability function (4.20) are:

$$\left.\begin{array}{r} \sum_{\chi_{\boldsymbol{p}} \in V} P_{KB}(\chi_{\boldsymbol{p}}) = 1 \\ P_{KB}[a \leqslant X_{\boldsymbol{p}} \leqslant b] = \sum_{\chi_{\boldsymbol{p}} \in [a,b]} P_{KB}(\chi_{\boldsymbol{p}}) \end{array}\right\}, \tag{4.21}$$

where a and b are lower and upper boundary values, respectively. The corresponding *probability density function* (PDF) may be defined as

$$P_{KB}[X_{\boldsymbol{p}} = \chi_{\boldsymbol{p}}] = \sum_{i=1}^{n} \beta_{\boldsymbol{p}_i} \delta_K(\chi_{\boldsymbol{p}} - \chi_{\boldsymbol{p}_i}), \tag{4.22}$$

where $\beta_{\boldsymbol{p}_i} = P[X_{\boldsymbol{p}} = \chi_{\boldsymbol{p}_i}]$ and $\delta_K(\chi_{\boldsymbol{p}} - \chi_{\boldsymbol{p}_i})$ is Kronecker's delta. A commonly encountered case is when the attribute $X_{\boldsymbol{p}}$ is related to another attribute $Y_{\boldsymbol{p}}$ via a physical law $Y_{\boldsymbol{p}} = \phi(X_{\boldsymbol{p}})$. If $\phi(\cdot)$ is an one-to-one function, the PDF of $Y_{\boldsymbol{p}}$ is given by

$$P_{KB}[Y_{\boldsymbol{p}} = \psi_{\boldsymbol{p}}] = \sum_{i=1}^{n} \beta_{\boldsymbol{p}_i} \delta_K(\psi_{\boldsymbol{p}} - \psi_{\boldsymbol{p}_i}), \tag{4.23}$$

where $\psi_{\boldsymbol{p}_i} = \phi(\chi_{\boldsymbol{p}_i})$ and $P_{KB}[Y_{\boldsymbol{p}} = \psi_{\boldsymbol{p}_i}] = P_{KB}[X_{\boldsymbol{p}} = \chi_{\boldsymbol{p}_i}]$. If $\phi(\cdot)$ is not an one-to-one function, then Eq. (4.23) should be replaced by

$$P_{KB}[Y_{\boldsymbol{p}} = \psi_{\boldsymbol{p}}] = \sum_{j=1}^{n} \eta_{\boldsymbol{p}_j} \delta_K(\psi_{\boldsymbol{p}} - \psi_{\boldsymbol{p}_j}), \tag{4.24}$$

where $\eta_{\boldsymbol{p}_j} = \sum_{i:\phi(\chi_{\boldsymbol{p}_i}) = \psi_{\boldsymbol{p}_j}} \beta_{\boldsymbol{p}_j}$ and $P_{KB}[Y_{\boldsymbol{p}} = \psi_{\boldsymbol{p}_i}] = P_{KB}[X_{\boldsymbol{p}} = \chi_{\boldsymbol{p}_i} : \phi(\chi_{\boldsymbol{p}_i}) = \psi_{\boldsymbol{p}_j}]$.

In the case of an attribute $X_{\boldsymbol{p}}$ with continuous values (e.g., soil sample weight, atmospheric pollutant concentration, wind velocity, and solid earth temperature), one defines the PDF as

$$f_{KB}(\chi_{\boldsymbol{p}}) = \lim_{d\chi_{\boldsymbol{p}} \to 0} \tfrac{1}{d\chi_{\boldsymbol{p}}} P_{KB}[\chi_{\boldsymbol{p}} \leqslant X_{\boldsymbol{p}} < \chi_{\boldsymbol{p}} + d\chi_{\boldsymbol{p}}]. \tag{4.25}$$

The PDF is basically a useful tool of formal probability analysis. It can be seen as a sort of a convenient vehicle to proceed from one point of the analysis to another; e.g., the PDF (4.25) is not a probability per se, but a function in terms of which interpretive probabilities can be defined in the case of continuous random variables. Some elementary yet noteworthy properties of the PDF are:

$$P_{KB}[a \leqslant X_{\boldsymbol{p}} \leqslant b] = \int_a^b d\chi_{\boldsymbol{p}} f_{KB}(\chi_{\boldsymbol{p}}) \in [0,\ 1], \tag{4.26}$$

and

$$P_{KB}[X_{\boldsymbol{p}} \in V] = \int_V d\chi_{\boldsymbol{p}} f_{KB}(\chi_{\boldsymbol{p}}) = 1. \tag{4.27}$$

Eq. (4.26) yields the formal result $P_{KB}[X_{\boldsymbol{p}} = \chi_{\boldsymbol{p}}] = \int_{\chi_p}^{\chi_p} d\chi_{\boldsymbol{p}} f_{KB}(\chi_{\boldsymbol{p}}) = 0$, which may look a little paradoxical. However, in practice one can write, to a good approximation, that

$$P_{KB}[X_{\boldsymbol{p}} \approx \chi_{\boldsymbol{p}}] = d\chi_{\boldsymbol{p}} f_{KB}(\chi_{\boldsymbol{p}}). \tag{4.28}$$

In many physical experiments, e.g., the measurement apparatus does not record a point attribute value but rather a small interval, say $[9.363,\ 9.365]$. Then $d\chi_{\boldsymbol{p}} = 9.365 - 9.363 = 0.002$, and under certain conditions one can use the approximation $P_{KB}[\underbrace{9.363 \leqslant X_{\boldsymbol{p}} \leqslant 9.365}_{\textit{actual event in physical experiment}}] = P_{KB}[\underbrace{X_{\boldsymbol{p}} \approx 9.364}_{\textit{round-off approximation}}] = 0.002 f_{KB}(9.364)$.

The so-called *cumulative distribution function* (CDF) defined as

$$F_{KB}(b) = P_{KB}[X_{\boldsymbol{p}} \leqslant b] = \int_{-\infty}^b d\chi_{\boldsymbol{p}} f_{KB}(\chi_{\boldsymbol{p}}) \tag{4.29}$$

is another useful probability function in the context of stochastic reasoning.

As we shall see in Chapter 5, the above elementary probability definitions can be readily extended to include $\chi_{\boldsymbol{p}_i}$ at several space–time points $\boldsymbol{p}_i$ ($i = 1, \ldots, k$), as well as several attributes linked by a logic operator or physical law of change. The continuous formulation is more suitable for mathematical manipulations, whereas the discrete formulation for practical implementations. This being the case, it is possible that one first studies an attribute in the continuous domain, and then discretizes it so that it can be used for practical purposes.

4.5 Quantitative Representations of Uncertainty

One cannot avoid noticing that the world element that needs to understand, assess, and confront uncertainty is probably the most random of them all: the human agent. The discussion so far provides sufficient theoretical and evidential support to the thesis that uncertainty is a phenomenon with many different and sometimes contradictory features (epistemic vs. ontic, positive vs. negative, unknown vs. unknowable aspects of the world, etc.). Correspondingly, there are more than one ways that the agent can define uncertainty in terms of probability. The uncertainty assigned to each possible realization of an attribute $X_{\boldsymbol{p}}$ may be seen as a simple linear function of the corresponding probability or as a more involved nonlinear function of the probability.

4.5.1 Linear Uncertainty Model

Perhaps the most straightforward definition of the uncertainty of a possibility (realization) $\chi_{\boldsymbol{p}}$ of $X_{\boldsymbol{p}}$ is: *Uncertainty of* $\chi_{\boldsymbol{p}}$= *Probability of* $\chi_{\boldsymbol{p}}$ *not being the case* given the epistemic situation of the agent. In symbolic terms,

$$U_{KB}[\chi_{\boldsymbol{p}}] = 1 - P_{KB}[\chi_{\boldsymbol{p}}] = P_{KB}[\neg\chi_{\boldsymbol{p}}], \tag{4.30}$$

where "¬" denotes the negation of possibility $\chi_{\boldsymbol{p}}$ (i.e., $\chi_{\boldsymbol{p}}$ is not the case). Eq. (4.30) expresses the a priori uncertainty associated with $X_{\boldsymbol{p}}$ about the occurrence of a realization $\chi_{\boldsymbol{p}}$, or equivalently, the uncertainty contained in the probability model P_{KB} about $\chi_{\boldsymbol{p}}$. "A priori" means that the above uncertainty considerations make sense only before the occurrence of a specific realization (obviously, there is no uncertainty after the actual occurrence of the previously unknown realization). In light of (4.30), the uncertainty U_{KB} and probability P_{KB} of an attribute $X_{\boldsymbol{p}}$ are both linked to the agent's assertion concerning $X_{\boldsymbol{p}}$'s state given the available KB. Eq. (4.30) is a simple yet considerably useful definition of uncertainty in the sense that it reveals certain important connections between uncertainty, probability, and stochastic logic. Clearly, $U_{KB}[\chi_{\boldsymbol{p}}] = 0$ when the possibility $\chi_{\boldsymbol{p}}$ is considered to be a certainty (before the event). On the other hand, $U_{KB}[\chi_{\boldsymbol{p}}] = 1$, when the agent is certain that $\chi_{\boldsymbol{p}}$ will turn out not to be the case. This is sort of paradoxical: according to Eq. (4.30), the agent's maximum uncertainty about $\chi_{\boldsymbol{p}}$ may be also seen as the agent's certainty about $\neg\chi_{\boldsymbol{p}}$. For illustration, consider the possibility: *The rainfall level in Sparta tomorrow will be* $\chi_{\boldsymbol{p}} = 0$ *cm*. Before the event, an agent asserts that this possibility cannot be the case based on the available KB (data sets, weather models, etc.). Instead, the agent asserts that it will rain for sure in Sparta tomorrow, i.e., $P_{KB}[\chi_{\boldsymbol{p}} = 0] = 0$, $P_{KB}[\chi_{\boldsymbol{p}} \neq 0] = 1$, and $U_{KB}[\chi_{\boldsymbol{p}} = 0] = P_{KB}[\chi_{\boldsymbol{p}} \neq 0] = 1$. For stochastic reasoning purposes, a number of interesting formulas can be derived from the uncertainty model (4.30). Some of these formulas are listed in Table 4.2, where $\chi_{\boldsymbol{p}_i}$ ($i = 1, \ldots, m$) are possible realizations of the attribute $X_{\boldsymbol{p}}$. For $m = 3$, Eq. (4.31) gives $U_{KB}[\chi_{\boldsymbol{p}_i} \vee \chi_{\boldsymbol{p}_j} \vee \chi_{\boldsymbol{p}_k}] = U_{KB}[\chi_{\boldsymbol{p}_i}] + U_{KB}[\chi_{\boldsymbol{p}_j}] + U_{KB}[\chi_{\boldsymbol{p}_k}] - U_{KB}[\chi_{\boldsymbol{p}_i} \wedge \chi_{\boldsymbol{p}_j}] - U_{KB}[\chi_{\boldsymbol{p}_i} \wedge \chi_{\boldsymbol{p}_k}] - U_{KB}[\chi_{\boldsymbol{p}_j} \wedge \chi_{\boldsymbol{p}_k}] + U_{KB}[\chi_{\boldsymbol{p}_i} \wedge \chi_{\boldsymbol{p}_j} \wedge \chi_{\boldsymbol{p}_k}]$. Eqs. (4.31)–(4.37) are consequences of Eq. (4.30) and the corresponding probability formulas. Eq. (4.33) assumes that none of the $\chi_{\boldsymbol{p}_i}$ is implied by the others. In Eqs. (4.34) and (4.35) the $\Lambda_{i=1}^{m} \chi_{\boldsymbol{p}_i}$ is logically

Table 4.2 Summary of linear uncertainty formulas

Disjunction (addition)	$U_{KB}[\mathrm{V}_{i=1}^{m}\chi_{p_i}] = \sum_{i=1}^{m} U_{KB}[\chi_{p_i}] - \sum_{i=1}^{m-1}\sum_{j=i+1}^{m} U_{KB}[\chi_{p_i}\wedge\chi_{p_j}] + \sum_{i=1}^{m-1}\sum_{j=i+1}^{m}\sum_{k=j+1}^{m} U_{KB}[\chi_{p_i}\wedge\chi_{p_j}\wedge\chi_{p_k}] + \ldots$	(4.31)
Conjunction (multiplication)	$U_{KB}[\Lambda_{i=1}^{m}\chi_{p_i}] \leqslant \sum_{i=1}^{m} U_{KB}[\chi_{p_i}]$	(4.32)
Logical independence	$U_{KB}[\Lambda_{i=1}^{m}\chi_{p_i}] = \sum_{i=1}^{m} U_{KB}[\chi_{p_i}]$	(4.33)
Logical inconsistency	$U_{KB}[\Lambda_{i=1}^{m}\chi_{p_i}] = 1$	(4.34)
	$U_{KB}[\mathrm{V}_{i=1}^{m}\chi_{p_i}] \leqslant 1$	(4.35)
Probabilistic independence	$U_{KB}[\Lambda_{i=1}^{m}\chi_{p_i}] = \sum_{i=1}^{m} U_{KB}[\chi_{p_i}] - \sum_{i,j=1}^{m} U_{KB}[\chi_{p_i}]U_{KB}[\chi_{p_j}] + \sum_{i,j,k=1}^{m} U_{KB}[\chi_{p_i}]U_{KB}[\chi_{p_j}]U_{KB}[\chi_{p_k}] - \cdots$	(4.36)
Entailment $(\chi_{p_i}; i = 1,\ldots,m) \therefore \chi_{p_q}$	$U_{KB}[\Lambda_{i=1}^{m}\chi_{p_i}] \geqslant U_{KB}[\chi_{p_q}]$	(4.37)

false ($P_{KB}[\Lambda_{i=1}^{m}\chi_{p_i}] = 0$). The results in Table 4.2 are valid in terms of different attributes, as well. As usual, in Eq. (4.37) the symbol "∴" means "entail" or "implicate." Chapter 6 will revisit the uncertainty model (4.30) in the context of stochastic reasoning.

4.5.2 *Logarithmic Uncertainty Model*

A more involved definition of uncertainty with strong links to information theory is in terms of the logarithmic function of the associated probability. Assume that the attribute X_p has two independent realizations χ_{p_i} and χ_{p_2} (e.g., tossing a coin with "$\chi_{p_1} = head$" and "$\chi_{p_2} = tail$"). Three conditions are widely accepted as valid: the X_p's uncertainty U_{KB} is a function of the corresponding probability P_{KB}, $U_{KB} = U(P_{KB})$; due to independency, the uncertainty about the combined outcome $\chi_{p_1} \wedge \chi_{p_2}$ is the sum of uncertainties about the separate realizations (uncertainty additivity), $U_{KB}(\chi_{p_1} \wedge \chi_{p_2}) = U_{KB}(\chi_{p_1}) + U_{KB}(\chi_{p_2})$; and the uncertainty about a realization increases as the probability of the realization decreases. As it turns out, the mathematical function that satisfies these conditions is logarithmic, as follows

$$U_{KB}(\chi_p) = \lambda \log_a P_{KB}^{-1}[\chi_p] = -\lambda \log_a P_{KB}[\chi_p], \tag{4.38}$$

where λ is a constant that depends on the logarithmic base a. As before, (4.38) expresses a priori uncertainty about the occurrence of χ_p (uncertainty contained in P_{KB} about χ_p).

It is noteworthy that Eq. (4.38) can be written as $U_{KB}[\chi_p] \propto \log_a 1 - \log_a P_{KB}[\chi_p]$,[24] which shows some formal analogy with Eq. (4.30): in terms of logarithms, the

[24] $\log_a 1 = 0$.

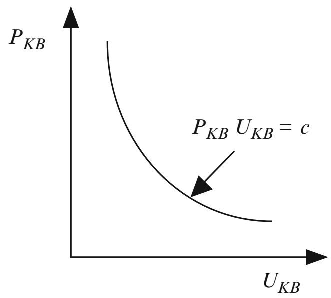

Fig. 4.4 Trade-off between U_{KB} and P_{KB}

uncertainty model (4.38) has an additive form as does the uncertainty model (4.30). The readers may notice that the uncertainty (4.30) is defined when $P_{KB}[\chi_{\boldsymbol{p}}] = 0$, in which case $U_{KB}[\chi_{\boldsymbol{p}}] = 1$. This is not necessarily valid for the uncertainty model (4.38). The latter model is linked to the trade-off relationship that asserts that the product of the probability P_{KB} of $\chi_{\boldsymbol{p}}$ and its uncertainty U_G cannot exceed a limit c, i.e.,

$$P_{KB}\, U_{KB} \leqslant c. \tag{4.39}$$

The trade-off relationship (4.39) is plotted in Fig. 4.4. For a fixed $\chi_{\boldsymbol{p}}$ value, the area under the curve $U_{KB} = U_{KB}(P_{KB})$ is $\int_{P_{KB}}^{1} d\rho\, U_{KB}(\rho) = c \int_{P_{KB}}^{1} d\rho\, \rho^{-1} = -c \log P_{KB}$, i.e., the uncertainty about the realization $\chi_{\boldsymbol{p}}$ is proportional to $-\log P_{KB} = \log P_{KB}^{-1}$, as in Eq. (4.38). *Data occasione*,[25] different versions of the trade-off relationship are found in the literature: physical law predictions trade-off precision with certainty (Duhem 1906); there is a trade-off between the evidential security of an estimate and its contextual detail (Rescher 2006); the brain (selectional system that operates *prima facie* not by logic but by pattern recognition) trades-off specificity and precision (Edelman 2006). Chapter 7 will revisit uncertainty in the sense of Eq. (4.38). Last, some more formal analogies may be drawn between the uncertainty definitions (4.30) and (4.38) above. Let $U_{KB,1} =$ Eq. (4.30) and $U_{KB,2} =$ Eq. (4.38). Then, it is a straightforward result that $U_{KB,2} = -\lambda \log_a[1 - U_{KB,1}]$ and $U_{KB,1} = 1 - a^{-\lambda^{-1} U_{KB,2}}$. Furthermore, in light of Eq. (4.39), one can start with the plausible uncertainty definition

$$U_{KB}(\chi_{\boldsymbol{p}}) = P_{KB}^{-1}[\chi_{\boldsymbol{p}}], \tag{4.40}$$

which assumes an inverse relation between uncertainty and probability (i.e., the more probable the occurrence of a realization $\chi_{\boldsymbol{p}}$ is, the smaller the uncertainty assigned to it). Since, for technical reasons, probabilities can be very small, it is convenient to work with logarithms so that the uncertainty model (4.40) becomes $U_{KB}(\chi_{\boldsymbol{p}}) = \lambda \log_a P_{KB}^{-1}[\chi_{\boldsymbol{p}}]$, which is Eq. (4.38).

[25] Given the opportunity, by the way, *Ειρήσθω εν παρόδω*.

Chapter 5
Stochastic Reasoning

When reason is against a man, a man will be against reason.

T. Hobbes

5.1 Lifting Isis' Veil

Sometime during the early fifth century BC, Heraclitus famously uttered: *Φύσις κρύπτεται φιλεί.*[1] Many centuries later, Werner Heisenberg famously postulated that "Not only is Nature stranger than we think, it is stranger than we can think." Was Heisenberg right, and what exactly he meant by "we can think"? The spirit of this book is based on the premise that the precise meaning of this sort of thoughts can attune IPS to new dimensions of human inquiry, change one's sense of what is possible and meaningful, and guide one toward unforeseen horizons of understanding.

Metaphorically speaking, Heraclitus' and Heisenberg's thoughts seem to converge to a common image of Nature using some sort of a "veil" or "mask" to deceive humans and make it difficult or even impossible for them to discover the truth. History-prone readers may recall that Nature has been allegorically identified with the goddess *Isis* of ancient Egypt. The statue of Isis covered in a black veil was erected on a tomb close to Memphis. On the statue's pedestal was engraved the inscription:

> I am everything that was, everything that is, that will be, and no mortal has yet dared to lift my veil.

The ancients believed that knowledge and truth were hidden beneath Isis' veil. The lifting of the veil represented the revelation of the truth, and to succeed in doing so is to become immortal. Accordingly, since ancient times philosophical investigations have focused on questions like: Is Isis (Nature) unknown or unknowable? Can the veil be removed from Isis (Nature) by reason, experiment, or intuition? Should the veil be removed, and what are the possible consequences?

---

[1] Nature loves to hide.

G. Christakos, *Integrative Problem-Solving in a Time of Decadence*,
DOI 10.1007/978-90-481-9890-0_5,

Perhaps, one should not be over-concerned about goddess' veil. After all, ancient Greeks expected their gods and goddesses to behave as human beings do. Humans are often masked from one another, and so do their gods. This is true in modern times, and perhaps even more so. The imaginative ways humans are masked from others, masked even from those who they love most are masterfully explored in Carolyn Parkhurst's 2003 novel *The Dogs of Babel*. Just as is the case with human behavior, all options are on the table: Nature's veil may be impenetrable, she may chose to lift the veil herself, or the veil can be finally removed using the tools of human inquiry. In the latter case, it is left to inquisitive minds to search for creative ways that could progressively, profitably, and safely lift Isis' veil, so to speak.

Resorting once more to metaphor, *stochastic reasoning*[2] is an attempt to lift Isis' veil using a synthesis of tools (abstract and intuitive, mathematical and physical, rational and empirical) provided by the sometimes productive-sometimes fruitless, sometimes enjoyable-sometimes agitating, sometimes exhilarating-sometimes discouraging, yet always fascinating dialectic between the human mind and Isis (Nature). The correspondence between the inner and the outer, the intellectual and the sensuous, the seer and the seen, is a daring attempt to visualize invisible Isis out of space and time. It is also an attempt to obtain a deeper understanding of the distinction between the Nature impressing itself on the mind and fashioning it, on the one hand, and the mind portraying Nature in its own creative way, on the other hand. A word of warning may be appropriate at this point. Following Niccolo Machiavelli's advice that "injuries should be inflicted all at once," this chapter exposes the readers to a good dose of mathematics.

5.2 Reasoning in a Stochastic Setting

Although many investigators would claim that they do not consciously practice formal reasoning, nevertheless, they often unwittingly practice an informal yet distinctive reasoning mode. This is true even in cases in which the investigator's reasoning begins simply with the recognition of clues. The matter is of considerable importance since it can effectively help the investigators scrutinize the main presumptions underlying their research techniques, improve their understanding of key concepts, test and reshape their intuition. It is surprising that recent debates concerning epidemiology research and its consequences in public health (Boffetta et al. 2008, 2009a, b; Blair et al. 2009) do not pay sufficient attention to the soundness of the logical reasoning that underlies each approach. Instead, the focus is on technical data analysis and empirical evidence. I will start with a review of traditional reasoning modes, and then will make the connection with uncertainty in a real-world setting.

[2] Already briefly introduced in Section 1.5.3.

5.2.1 Basic Reasoning Modes

It has been said that we live in a sound-bite society, in which it is the simple issues that predominantly attract people's attention. According to this perspective, if an idea cannot be presented on a bumper sticker, it has little or no chance to succeed. But this does not mean that one has to give in to hopelessness, which is how the story of stochastic reasoning unfolds.

5.2.1.1 Elements of Reasoning

Generally speaking, reasoning is a thought process that involves arguments (sentential, syntactic, symbolic, or numerical). An argument is a mental construct that starts with specified premises or hypotheses (data, facts, observations or measurements, statements, assumptions, and physical laws), and develops certain conclusions or consequences (problem-solutions, attribute predictions across space–time, system evaluations, and new laws). There is a list of so-called indicator words, which point out which part of the argument is the premises and which the conclusions. Words like, "assuming that," "if," "because," "since," and "by virtue of" indicate the beginning of premises. On the other hand, words like "therefore," "hence," "so," "consequently," and "it follows that" indicate the beginning of conclusions. For illustration purposes, Table 5.1 gives a list of common arguments. Whatever is above the horizontal line is a premise and whatever is below the line is a conclusion. The symbol "∴" means "entails," or "implies" in a broad sense (i.e., it is valid for any rational agent). The readers may notice that (5.1) is a commonly used argument. When the focus of the study is a physical attribute $X_{\boldsymbol{p}} = X_{s,t}$, the premises and the conclusions may take a symbolic and/or numerical form, see argument (5.2); the $X_{\boldsymbol{p}}$ changes across space–time according to physical law, which means that the "premises" are causally linked to the "conclusion" (as we saw in Section 1.2.3, this is a key premise of stochastic reasoning). Measurement and prediction values in Eq. (5.2) are in suitable numerical units.

Table 5.1 Examples of arguments

Every Thessalos is a good horserider *Alkividas is not a good horserider* (5.1) ——— ∴ *Alkiviadis is not Thessalos*	$X_{s,t} = 0.9^t X_{0,0} + 2.1 s^2 t$ (*Physical law*) $X_{0,0} = 1.3$ (*Measurement*) (5.2) ——— ∴ $X_{2,1} = 9.57$ (*Law prediction*)
All Romans spoke Latin *Nero spoke Latin* (5.3) ——— ∴ *Nero was Roman*	*All Romans spoke Latin* *Descartes spoke Latin* (5.4) ——— ∴ *Descartes was Roman*
All Italian − Americans are tall *Danny DeVito is an Italian − American* (5.5) ——— ∴ *Danny DeVito is tall*	*All men are mortal* *Danny DeVito is a man* (5.6) ——— ∴ *Danny DeVito is mortal*

Table 5.2 Possible valid argument forms

Premise	Conclusion
True	True
False	False
False	True

In terms of logic, an argument may be concerned with a number of things. It could be for or against a specific thesis, suggest a solution of a problem, or lead to a novel result. In evaluating an argument one is basically interested about two items: (*i*) Are the premises true? (*ii*) Assuming that the premises are true, what kind of support do they offer to the conclusion? Although Element *i* is not the business of logic, it is of great concern in scientific investigations. Element *ii*, on the other hand, is definitely the business of logic. Valid argument is one that cannot have true premises followed by wrong conclusions (i.e., if the premises are true then one is assured that the conclusion is also true). Three classical premise-conclusion combinations associated with a valid argument are shown in Table 5.2. The word "possible" in the legend of Table 5.2 implies that a true premise and a true conclusion are not, by themselves, enough to have a valid argument; it must also hold that to assert the premise and deny the conclusion would involve a contradiction (i.e., it will be logically inconsistent). It is instructive to consider the arguments (5.3)–(5.4) in Table 5.1. Neither of these arguments is necessarily a logically valid argument (even when the premises are true, one is not assured that the conclusion is also true). As a matter of fact, it is on historical grounds that one can say that the argument (5.3) is valid (Nero was Roman), whereas the argument (5.4) is wrong (Descartes was not Roman). In fact, when the premises are indeed true (which is not the task of logic but of science, history, etc., to confirm) the argument is more than valid – it is sound. Consider the argument (5.5) in Table 5.1. This is a valid but not a sound argument (because, obviously, the premise that "All Italian-Americans are tall" is not true). Now consider the argument (5.6) in Table 5.1. This is a valid and sound argument (both premises are true in the real-world).

Rather simple arguments like the above can offer insights concerning sound reasoning that can deepen conscious awareness and improve one's capacity for experience. As we will see later, these qualities play a key role in the development of an IPS that accounts for conditions of in situ uncertainty. Possible insights include the following: (*a*) A rigorous formalization may guarantee general logical validity but not substantive soundness (scientific or otherwise). An argument may be perfectly valid from a purely formal viewpoint, and yet make no sense from the viewpoint of science or even common sense. Hence, one needs more than pure logic to establish the truth of many real-world arguments. (*b*) It is doubtful that most real-world arguments fit the strict "premises-conclusion" formalization. Instead, there is considerable uncertainty about several aspects of the premises (e.g., physical law parameters and associated measurements are often uncertain). The "theory–evidential support" relationship is not as definite as the formalization may assume (e.g., general relativity theory is assumed valid in a wider physical domain than that covered by the available data). (*c*) The logical process used in Arguments (5.5)–(5.6) offers a complete confirmation, whereas the process used in (5.3)–(5.4) only provides a partial confirmation. It is noteworthy that many everyday life arguments are based on the latter rather than the former logical process. Below, I will first examine the two traditional reasoning modes, deduction and induction, and then will briefly discuss hypothetico-deduction, which is a reasoning mode that became popular mainly during the last century. Some of the *pros* and *cons* of the three modes will be pointed out as well.

5.2.1.2 Deductive Reasoning

Deduction or deductive reasoning is reasoning from the general to the particular or less general. It evaluates the arguments on the basis of validity, i.e., it allows only valid arguments. The premises, if they were true, guarantee the truth of the conclusion, which means that deductive inferences preserve truth. For illustration purposes, let $X_{\boldsymbol{p}_i}, Y_{\boldsymbol{p}_j}, Z_{\boldsymbol{p}_k}$ etc. denote space–time attributes with possible realizations $\chi_{\boldsymbol{p}_i}, \psi_{\boldsymbol{p}_j}, \zeta_{\boldsymbol{p}_k}$ etc. ($\boldsymbol{p} = (\boldsymbol{s}, t)$). The attribute realizations $\chi_{\boldsymbol{p}_i}$ and $\psi_{\boldsymbol{p}_j}$ may be linked by means of a causal relationship in a physical continuum (Fig. 5.1). The symbol "$\neg$" denotes negation (e.g., $\neg\chi_{\boldsymbol{p}_i}$ means that it is not the case that the realization $\chi_{\boldsymbol{p}_i}$ is true). The symbol "$\wedge$" denotes conjunction ($\chi_{\boldsymbol{p}_i} \wedge \psi_{\boldsymbol{p}_j}$ means that both the realizations $\chi_{\boldsymbol{p}_i}$ and $\psi_{\boldsymbol{p}_j}$ are true). The symbol "$\vee$" denotes disjunction ($\chi_{\boldsymbol{p}_i} \vee \psi_{\boldsymbol{p}_j}$ means that either $\chi_{\boldsymbol{p}_i}$ or $\psi_{\boldsymbol{p}_j}$ is true). The symbol "$\rightarrow$" denotes implication ($\chi_{\boldsymbol{p}_i} \rightarrow \psi_{\boldsymbol{p}_j}$ means that if $\chi_{\boldsymbol{p}_i}$ is true, then $\psi_{\boldsymbol{p}_j}$ is true).[3] The symbol "$\leftrightarrow$" denotes equivalence ($\chi_{\boldsymbol{p}_i} \leftrightarrow \psi_{\boldsymbol{p}_j}$ means that $\chi_{\boldsymbol{p}_i}$ is true if and only if $\psi_{\boldsymbol{p}_j}$ is true).[4] The symbol $\chi_{\boldsymbol{p}_i} \leftrightarrow \psi_{\boldsymbol{p}_j}$ also implies that $\chi_{\boldsymbol{p}_i} \wedge (\neg\psi_{\boldsymbol{p}_j})$ is a contradiction ($\chi_{\boldsymbol{p}_i} \wedge (\neg\psi_{\boldsymbol{p}_j}) \leftrightarrow \ell$), whereas $\chi_{\boldsymbol{p}_i} \vee (\neg\psi_{\boldsymbol{p}_j})$ is a tautology, ($\chi_{\boldsymbol{p}_i} \vee (\neg\psi_{\boldsymbol{p}_j}) \leftrightarrow \tau$). The symbol "$\langle \cdot \mid \cdot \rangle$" denotes that whatever is on the right of the vertical line has the property on the left of the line. If A is a set of realizations $\chi_{\boldsymbol{p}_i}$, the $\langle \Theta \mid A \rangle$ and $\left\langle \Theta \mid \chi_{\boldsymbol{p}_i} \right\rangle$ denote, respectively, that the set A or just a realization $\chi_{\boldsymbol{p}_i}$ has the property Θ; lastly, the symbol "$\in$" means "belongs to." Logic operators can be combined in different ways leading, to a variety of deductive reasoning results that are not always obvious a priori. In Chapter 6, we will

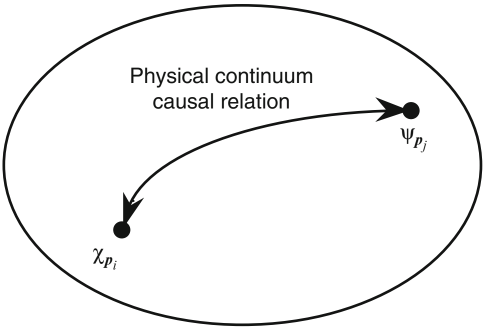

Fig. 5.1 Realizations of two different attributes linked by a physical continuum

[3] What is asserted by implication is that $\neg(\chi_{\boldsymbol{p}_i} \wedge (\neg\psi_{\boldsymbol{p}_j}))$, i.e., it is not the case that $\chi_{\boldsymbol{p}_i}$ and not $\psi_{\boldsymbol{p}_j}$.
[4] Equivalence is a strong logic operator that means the same as $(\chi_{\boldsymbol{p}_i} \rightarrow \psi_{\boldsymbol{p}_j}) \wedge (\psi_{\boldsymbol{p}_j} \rightarrow \chi_{\boldsymbol{p}_i})$.

Table 5.3 Deductive reasoning rules in terms of attribute realizations[5]

Modus tollens $\chi_{p_i} \to \psi_{p_j}$ $\underline{\neg\psi_{p_j}}$ $\therefore \neg\chi_{p_i}$	Modus ponens $\chi_{p_i} \to \psi_{p_j}$ $\underline{\chi_{p_i}}$ $\therefore \psi_{p_j}$	Simplification $\underline{\chi_{p_i} \wedge \psi_{p_j}}$ $\therefore \chi_{p_i}$	Conjunction $\underline{\chi_{p_i}, \psi_{p_j}}$ $\therefore \chi_{p_i} \wedge \psi_{p_j}$
Absorption $\underline{\chi_{p_i} \to \psi_{p_j}}$ $\therefore \chi_{p_i} \to (\chi_{p_i} \wedge \psi_{p_j})$	Excluded middle $\chi_{p_i} \to \psi_{p_j}$ $\underline{\neg\chi_{p_i} \to \psi_{p_j}}$ $\therefore \psi_{p_j}$	Disjunctive syllogism $\chi_{p_i} \vee \psi_{p_j}$ $\underline{\neg\chi_{p_i}}$ $\therefore \psi_{p_j}$	Constructive dilemma $\chi_{p_i} \vee \psi_{p_j},$ $\underline{(\chi_{p_i} \to \zeta_{p_k}) \wedge (\psi_{p_j} \to \omega_{p_q})}$ $\therefore \zeta_{p_k} \vee \omega_{p_q}$
Contradiction $\chi_{p_i} \to \psi_{p_j}$ $\underline{\chi_{p_i} \to \neg\psi_{p_j}}$ $\therefore \neg\chi_{p_i}$	Addition $\underline{\chi_{p_i}}$ $\therefore \chi_{p_i} \vee \psi_{p_j}$	Hypothetical syllogism $\chi_{p_i} \to \psi_{p_j}$ $\psi_{p_j} \to \zeta_{p_k}$ $\ldots$ $\underline{\upsilon_{p_q} \to \omega_{p_m}}$ $\therefore \chi_{p_i} \to \omega_{p_m}$	Direct generalization $\langle \Theta \mid A \rangle$ $\underline{\chi_{p_i} \in A}$ $\therefore \left\langle \Theta \,\middle|\, \chi_{p_i} \right\rangle$

see how these logic operators (as well as the rules of Tables 5.3 and 5.4) can be considered in a stochastic logic milieu in conditions of uncertainty.

Table 5.3 provides a useful list of deductive argumentation rules in terms of attribute realizations. The same rules are valid if the attribute realizations are replaced with statements A, B, C... of everyday language. Deductive reasoning is defined in a very precise way: it is the kind of reasoning in which it is logically impossible for the premises to be true and the conclusion false. According to Karl Popper (1963: 51), "The role of deductive logic reasoning remains all-important for the critical approach...because only by purely deductive reasoning is it possible for us to discover what our theories imply, and thus to criticize them effectively." Mathematics is based on deductive reasoning, which is why mathematics possesses all the *pros* and *cons* of this mode of reasoning. In the case of deduction, the conclusion asserts no more information than is asserted in the premises, and generally has nothing to say about the validity of these premises per se (which is the business of science).[6] In fact, the deductive process is so precise albeit mechanical and essentially content-free that Bertrand Russell once emphatically wrote that

> Pure mathematics consists entirely of such asseverations as that, if such and such a proposition is true of anything, then such and such another proposition is true of that thing... It's essential not to discuss whether the proposition is really true, and not to

[5] Otherwise said, these are realizations of the spatiotemporal random field model (Section 5.3 below).

[6] Whereas in induction the conclusion goes beyond, i.e. "amplifies," the content of premises (see below).

Table 5.4 Inductive reasoning rules in terms of attribute realizations

Partial confirmation	Partial rejection	Causal generalization
$\chi_{p_i} \to \psi_{p_j}$ ψ_{p_j} $\therefore \chi_{p_i}$ is probable	$\chi_{p_i} \to \psi_{p_j}$ $\neg\chi_{p_i}$ $\therefore \neg\psi_{p_j}$ is probable	ψ_{p_j} follows χ_{p_i} $\therefore \chi_{p_i}$ is probably the cause of ψ_{p_j}
Analogy $\left\langle \Theta_i \middle| \chi_{p_i}, \psi_{p_i} \right\rangle$ $i = 1, \ldots, N-1$ $\left\langle \Theta_N \middle| \chi_{p_N} \right\rangle$ $\therefore \left\langle \Theta_N \middle| \psi_{p_N} \right\rangle$ is probable	Simple enumeration $\left\langle \Theta \mid \chi_{p_i} \right\rangle \begin{cases} \chi_{p_i} \in A \\ (i = 1, 2, \ldots, N) \end{cases}$ $\therefore \langle \Theta \mid A \rangle$ is probable	Statistical generalization $\langle \Theta \mid S_i \rangle \begin{cases} S_i \subset \Omega \\ (i = 1, 2, \ldots, N) \end{cases}$ $\therefore$ $\langle \Theta \mid \Omega \rangle$ is probable

> mention what the anything is of which it is supposed to be true... If our hypothesis is about anything and not about some one or more particular things, then our deductions constitute mathematics. Thus mathematics may be defined as the subject in which we never know what we are talking about, nor whether what we are saying is true.

The take-home message is that one should be aware of the *seduction-by-deduction* temptation, since in many cases a direct, uncritical implementation of deductive reasoning in real-world applications may be like using both feet to test the depth of the river.

5.2.1.3 Inductive Reasoning

Induction is reasoning from the particular to the general. It evaluates the arguments on the basis of *probability* (may allow invalid arguments that are, though, highly probable arguments on the basis of the premises). The premises, if they are true, make probable the truth of the conclusion. Accordingly, induction includes argument forms in which the conclusion does not follow necessarily from the premises (as is the case of valid deductive reasoning), but, instead, is inferred as likely. Otherwise said, inductive reasoning assures one that the conclusion is likely, but not that it is certain, and it analyzes risky arguments using probabilistic statements. There exist several classifications of inductive reasoning. One classification distinguishes between induction by enumeration and induction as inference to the best explanation or abduction. In *enumerative* induction, a conclusion is derived on the basis of a large and representative attribute sample. In *abductive* inference, a conclusion concerning one thing is obtained as the best explanation of something else. In other words, the basic difference between enumeration and abduction is that, while the former proceeds from a large and representative sample to an unrestricted conclusion, the latter proceeds from a single observed attribute or phenomenon to the explanation of another attribute or phenomenon. Abduction is frequently employed in scientific investigations; e.g., although electrons themselves cannot be seen, scientists conclude that they exist since such a conclusion provides the best possible explanation of certain observations. Table 5.4 gives a list of inductive rules. Inductive arguments are *partial confirmation* arguments to which one can assign probability values that depend on the available knowledge, i.e., given the historical knowledge available, the probability that Nero was Roman tends to one, whereas the probability that Descartes was Roman tends to zero. In less developed fields the violation of the reasoning rules of Tables 5.3 and 5.4 frequently leads to problematic results. In clinical research, e.g., the probabilistic nature of the inductive rules in Table 5.4 is often ignored, and the rules are misinterpreted as deductive. The matter will be studied in Section 6.1, after the random field concept is introduced in Section 6.3 that follows. As in Table 5.3, the inductive rules of Table 5.4 remain valid if the attribute realizations are replaced with statements.

Epicureans have held that there exist shortcuts to happiness, but induction is not one of them. As it turns out, the direct, uncritical implementation of pure or naive induction in scientific research can be problematic. David Hume (Section 2.2.9) was probably the first to put into question the legitimacy of pure induction, due to its circularity: the only grounds we have for trusting induction are circular, in the sense that inductive inferences are justified on the basis that these inferences have worked in the past. Remarkably, one of the best-known responses to Hume's challenge is one of desperation: as long as induction works, one can ignore any circularity problems. This is an inadequate argument, of course, that essentially applies to everything under the Sun. And if this is the best argument pure induction can come up with, then too bad for pure induction. Nevertheless, even this simplistic argument is not problem-free in its implementation: What is the meaning of the term "works" in the setting of the above argument? Under what special conditions the argument applies? When pure induction fails, what we learn about the source of its failure? Its inability to convincingly respond to these and similar questions has caused many scientists to seriously doubt the effectiveness of pure induction. Sir Peter Medawar (1969: 11) jokingly remarked that, "If anyone working in a laboratory professed to be trying to establish laws of Nature by induction, we should begin to think he was overdue for leave." Surprisingly, some empirical data analysts still remain in an unconscious bondage to outdated practices of pure induction that have been widely repudiated or otherwise allowed to fade away (see, also, Sections 8.2.2 and 9.4).

The above considerations by no means imply that pure induction has no place in scientific inquiry, rather its implementation makes sense in certain special cases that must be carefully considered. Most investigators would agree that in real-world studies one rather employs valid combinations of inductive and deductive elements; e.g., induction is used in the determination of premises (first stage), and the verification of conclusions (third stage), whereas deduction is used in the derivation of conclusions from premises (second stage). Due to its importance in scientific inquiry, the matter is discussed in other parts of this book.

5.2.1.4 Hypothetico-Deductive Reasoning

The hypothetico-deductive mode of reasoning is as follows: a hypothesis or theory is formulated concerning a problem, its consequences (e.g., predictions) are worked out, and then tested by means of observations and/or experiments. A test that could and does run contrary to the consequences of the hypothesis or theory is taken as a *falsification* of the hypothesis or theory (Popper 1963; see also Section 1.1.2). On the other hand, a test that could but does not run contrary to the hypothesis or theory corroborates the hypothesis or theory. In hypothetico-deductive reasoning, a mental entity (hypothesis, theory, or solution) needs to be testable in some definite way, i.e. be capable of proven wrong (falsified) under certain conditions, in which case the entity is termed falsifiable. A falsifiable entity is provisionally accepted until it is falsified.

Popper claimed that for a construct to be scientific, it must satisfy the conditions of the above framework. As considered by him, falsification demands absolute specificity, in which case probabilistic statements are not directly falsifiable. The statement "It will probably rain in Paris tomorrow," e.g., is not directly falsifiable in the above sense, because it is not a clear-cut statement. The latter is the case of mathematical statements, since they are tautological (proving mathematical theorems involves reducing them to tautologies, i.e., reducing the negative to a contradiction). The above imply some limitations of both, the conceptual framework of falsification and its practical usefulness. Imre Lakatos (1976, 1978a, b), e.g., argued that there is no falsification before the emergence of a better theory – theories and models are more often repaired than they are refuted.

5.2.2 Transition to Stochastic Thinking

The preceding discussion of reasoning modes provides a starting point from which to interpret as significant the conceptual gaps in standard logic between formal rules and in situ reality. Undoubtedly, the implementation of a reasoning mode in most in situ situations should involve the notions of probability and uncertainty. Given the multisourced in situ uncertainty, failing to include a suitable probability theory in the scientific field can be an obstacle to the field's progress. In this spirit, Paul W. Glimcher (2004: 177) maintained that, "The fundamental limitations which neurobiology faces today is a failure to adequately incorporate probability theory into the approaches we use to understand the brain."

5.2.2.1 A Slippery Affair and Its Psychology Connections

Having said that, it must not escape the readers' attention that reasoning in terms of probabilities can be a slippery affair. For Charles Sanders Peirce, "This branch of mathematics is the only one, I believe, in which good writers frequently get results entirely erroneous." In a similar vein, George N. Schlesinger (1991: 16) writes:

> The susceptibility to error is caused by allowing oneself to be guided too much by intuition and common sense. In probabilistic reasoning, more often than elsewhere, things are not what they seem, and untutored innate intelligence may frequently prove an unreliable guide.

These probability features are sometimes so difficult to comprehend that practitioners armed with only a superficial knowledge of probability theory, often make nonsensical claims (see, also, Sections 6.1, 6.3 and 9.4). Jeffrey S. Rosenthal (2006) offers some insight why human intuition is often very bad in guessing probabilities. Ola Svenson (2008) gives a psychological perspective on why in many cases human intuition is completely wrong. Furthermore, a few decades ago, Amos Tversky and Daniel Kahneman (1973, 1982) published some results suggesting that people have serious difficulties with probabilistic reasoning. They claimed that much of people's thinking under conditions of uncertainty is based merely on heuristics[7] (Workman and Reader 2004). Tversky and Kahneman attributed the poor performance of the study participants to their using heuristics: representative bias (participants are misled by what seems to be representative of the real-world), and base-rate neglect (participants failed to take prior probabilities into account). The response of the evolutionary psychology school was that, while it is true that people show rather poor intuitions when making decisions under conditions of uncertainty, however, this is due to the way things are presented to them. In many cases, e.g., people are presented with problem formulations that their minds are not evolutionary adapted to cope with. In particular, Leda Cosmides and John Tooby (1996) presented some results suggesting that when a problem is presented to a group of study participants in terms of single-case probabilities, most of them derive an incorrect solution. However, when the same problem is presented to the same group of participants in terms of frequencies, the majority of them derive the correct solution. The explanation of this apparent paradox is that while our ancestors have gained considerable benefits from evolving frequency-sensitive mechanisms, they have found little use for single-case mechanisms, in case the latter had been evolved. Two main conclusions could be drawn concerning the above views that seek to explain an agent's difficulties with probabilistic thinking: the heuristics perspective focuses on the irrationality of human reasoning, whereas the evolutionary perspective properly emphasizes its adaptive rationality. The former perspective seeks explanations in terms of proximate mechanisms, whereas the latter rather stresses ultimate explanation. A matter of significant interest is to assess how these different perspectives can affect the IPS approach that the agent chooses to use under conditions of uncertainty. This includes the solution of in situ problems in the physical and health sciences alike.

In an attempt to deal effectively with the state of affairs described above, stochastic reasoning requires from the investigator considerable levels of introspection and interpenetration, in addition to formal derivations. Unlike the mainstream paradigm, in the stochastic reasoning milieu, uncertainty characterizes not only inductive but deductive modes of argumentation too. Accordingly, logical derivations are not certain but have realistic probability values assigned to them. For reasons discussed in Sections 1.2.3, 4.3.1 and 4.3.2, uncertain attributes of a real-world system are usually linked to other uncertain attributes via physical or

[7] Heuristics are short-cut solutions to a problem, which, while are often quick and easy (or, in some cases, "quick and dirty") to implement, do not guarantee a correct solution.

logical relations. Even when an attribute is known with certainty, in situ relations most often link it to other attributes to which they assign probability values. Only in the rare case that the strict dependency of deductive reasoning connects one attribute to another the certainty of the first can be transferred to the second. As a consequence,terms like "probable," "causation," "implication," "contradiction," and "conditional" need to be re-interpreted in the appropriate contextual settings.

5.2.2.2 The Relationship Between Logic and Psychology

Continuing our discussion of the role of psychology in human reasoning, I will start with a real-world example that is paradoxical and at the same time somehow entertaining. The statements $P =$ *In favor of family values* and $C =$ *In favor of assault weapons* logically should represent mutually inconsistent or exclusive possibilities. Said otherwise, occurrence of one of them makes the occurrence of the other highly improbable. Yet public opinion polls show a clear shifting of American attitude toward $P \wedge C$, an astonishing result that belongs to the sphere of psychology rather than logic. As far as the relationship between logic and psychology is concerned, the readers are reminded that the two contradictory viewpoints traditionally considered are: (*a*) logic as a tool for exploring standards of human reasoning (*philosophical* viewpoint) and (*b*) logic as a quarry for extracting hypotheses concerning human thought processes (*psychological* viewpoint). Viewpoint *a* has a normative structure, whereas Viewpoint *b* has a rather descriptive structure. Concerning Viewpoint *a*, it is known that mathematical (deterministic) logic assumes a closed system with controlled environment. And even within this system, logic cannot demonstrate whether a possibility expresses an objective truth or not. It can only prove the validity of a possibility relative to other possibilities that an agent already knows to be true or false. Despite the usefulness of Viewpoint *b* in certain psychological investigations, it is considered of rather limited value outside these investigations (Macnamara 1994).

In view of the above considerations, the objective of stochastic reasoning is to reshape the relationship between logic and psychology in ways that enhance the experience of the investigating agents involved: stochastic reasoning seeks a fruitful synthesis of Viewpoints *a* and *b* that accounts for the fact that standard logic does not constitute the entire thinking process, but is only part of it; the synthesis incorporates uncertainty due to multiple sources (linked to the theory of knowledge or reality itself); and also confronts the fact that an agent's thinking in a real-world situation is a much more sophisticated process than the mechanistic scheme assumed by standard logic. In a sense, then, stochastic reasoning suggests that logic and psychology mutually constrain each other in an analogous way that mathematics and physical sciences constrain each other. Logic, e.g., could provide a rigorous language in which to express mental states and formulate these expressions in mathematical terms, which can be used in IPS under conditions of in situ uncertainty and space-time heterogeneity (Chapter 3). Human understanding and creativity are often richer than standard logic, indeed, which is content-insensitive and ignores that agents operate in an open system rather than in the idealistic closed system of formal logic. In so far as understanding thinking changes thinking, stochastic reasoning needs to substantially enrich and even modify formal logic, if it is to incorporate in situ situations that currently elude it. Stochastic reasoning expresses a cognitively general viewpoint (where the agent can only know that there exist some entities that have a certain feature), rather than a cognitively specific viewpoint (in which the agent definitely knows the exact entities that have this feature). It is more reasonable, e.g., to claim that due to its doctors' high qualifications, most of the patients who have open-heart surgery in the *St. Therese of Liseux* hospital survive (one may even be able to provide probabilities of survival for individual patients), rather than to claim to know exactly which patients will survive. In some special cases the *cognitive general* may be reduced to the *cognitive specific*. For example, when one knows with certainty all the input parameters and coefficients of a stochastic law (Section 5.5.3 below), the associated probability distributions reduce to single values, and the solution of the law becomes deterministic. But, this is a rather unlikely scenario in the vast majority of in situ situations. Last but not least, stochastic reasoning is purposive, which means that it delivers the agent's values and principles. This is a definite advantage, since any kind of reasoning, regardless of how rigorous and sound it is, if it lacks values, is of limited use or even dangerous in human affairs.

5.2.2.3 Some Distinctions

For procedural purposes, it is important to distinguish between three key fields: probability theory, statistics, and stochastics. As described in Collani (2008), "Probability theory develops 'mathematical concepts' independently of their usefulness. Statistics develops methods for analyzing large data sets in order to detect stabilities;" whereas "Stochastics represents a conceptual and theoretical basis covering all aspects which are involved in the scientific process of making predictions." Failing to acknowledge the key differences between these fields can lead to misconceptions, such as that stochastics is merely akin to descriptive statistics, or that spatial statistics includes both stochastic modeling and geostatistics (Myers 2006).

Noteworthy limitations of mainstream statistics that have been pointed out in the literature include (e.g., Wang 1993; Sivia 1996; Christakos 2000; Hyman 2006): (*i*) It is dominated by symbolic thought and not the free exchange between meaning and the empirical world, or the creative thought that is open to the new and risky. (*ii*) Substantive inadequacy of assumptions, like statistical independency and stability, which do not account for the physics of space–time. (*iii*) Lack of rigorous mechanisms to incorporate important forms of core knowledge (natural laws, primitive equations, social structures, etc.). (*iv*) Many tests entail serious logic problems and are often irrelevant to the objectives of the study (e.g., a statistical test states the probability of the observation given that a null hypothesis is true, whereas scientific investigation seeks the probability that the null hypothesis is true given the observation). (*v*) Analysis often relies on a collection of data processing recipes and number-crunching software (pattern fitting, trend projection, regression analysis, copula technology, etc.) that are introduced on the basis of mere convenience than sound reasoning and scientific insight –which is probably why Thomas Mikosch (2006b: 61) made a rather pessimistic comparison: "Living in the twenty-first century, we stand on the shoulders of giants such as Kolmogorov, Levy, Wiener and Cramer who did things not just because they could or because it was convenient."

To avoid the above limitations, stochastic reasoning assumes a very different conceptual structure than mainstream statistics. It focuses on deep theory (founded on natural laws, phenomenological representations, and epistemic principles) that enhances its scientific content and makes it a central force in the realistic study of natural systems. This is the kind of reasoning that can incorporate, *inter alia*, the sophisticated mathematics of stochastics, which has been very successful in the study of such diverse phenomena as contaminant transport in environmental media, atmospheric turbulence, electromagnetic wave propagation through atmosphere, large-scale systems linked to disease and mortality, epidemic propagation, embryonal formative processes, and organic molecules organizing themselves into organisms of increasing complexity through random chemical processes. Stochastic reasoning is endorsed with a solid theoretical background, a sound methodology, and a useable set of tools to study complex in situ situations associated with several possible "scenarios" of how a system or attribute might change in space–time under conditions of uncertainty, rather than a single yet unrealistic "scenario." As a matter of fact, due to its inevitably high level of sophistication, working in the field of stochastic reasoning requires a proportionally high level of intellectual effort on behalf of the investigator, who should not expect to be rewarded with a trip to the exotic Rondônia.[8] Instead of the mouthwatering *Caruru do Pará*, pure intellectual satisfaction most probably will be the theorist's only reward.

5.2.2.4 Interpretive Matters

In sum, nothing less is asked of an investigator today than to be at the same time within and outside things. The challenge of using stochastic reasoning in situ is often not in its formal component, but in the validity of its interpretive component in the specific application that goes beyond pure mathematics into the realms of physical knowledge and empirical observation. Interpretation issues are relevant when one needs to establish correspondence rules between natural attributes and formal mathematics that describe them, to measure and test the formal structure or to justify the methodological steps. This does not intend to imply that the two components are totally independent or merely linked by correspondence rules. Instead, the formal and the interpretive form an integrated whole. As such, the

[8] Region in Brazil that has been the theater of NASA's field-data acquisition campaigns.

fruitful interaction of formal and interpretive investigations plays a crucial role in the successful application of stochastic reasoning in real-world IPS. The essential connection between formal and interpretive components has been astonishingly productive, in both ways: formal techniques provide the means for understanding a phenomenon beyond sense perceptions, and interpretive investigations lead to new and more powerful formal techniques.

In short, stochastic reasoning lies at the interface of logic and empirical evidence, with strong ties to philosophy, linguistics, sociology, psychology and cognitive science. In the human inquiry milieu, stochastic reasoning acts as an intellectual catalyst that shows how different topics ran naturally into each other. Accordingly, stochastic reasoning needs to conceal any antagonistic demands of in situ observation and theory-based interpretation, which implies that the meaning of logic operators may change in the stochastic reasoning context. The strict determinism of the formal logic operators ($\wedge$, $\vee$,$\neg$, $\rightarrow$, $\leftrightarrow$) discussed in the previous sections is replaced by the reasonable indeterminism of stochastic reasoning. In other words, the meaning of the operators is re-interpreted to account for the uncertainty of the premises, the conclusions, and the operator-based process itself. For example, in formal logic, $\chi_{\boldsymbol{p}} \wedge \psi_{\boldsymbol{p}}$ denotes that both attribute realizations $\chi_{\boldsymbol{p}}$ and $\psi_{\boldsymbol{p}}$ are definitely true. But in stochastic reasoning, $\chi_{\boldsymbol{p}} \wedge \psi_{\boldsymbol{p}}$ means: "Agent's assertion that $\chi_{\boldsymbol{p}}$ is true and the agent's assertion that $\psi_{\boldsymbol{p}}$ is true." These assertions are not definite but, rather epistemic, i.e., they are conditioned on the available knowledge, which means that to each assertion (or, more generally, to any combination of assertions) one can assign a probability value. Also, instead of explaining a fallacy by trying to show that a valid realization $\chi_{\boldsymbol{p}}$ of the attribute $X_{\boldsymbol{p}}$ can cause an invalid realization $\psi_{\boldsymbol{p}}$ of another attribute $Y_{\boldsymbol{p}}$ (standard logic), it makes more sense to show that a probable realization $\chi_{\boldsymbol{p}}$ can cause an improbable realization $\psi_{\boldsymbol{p}}$ (stochastic reasoning). This approach may involve natural laws that link $X_{\boldsymbol{p}}$ and $Y_{\boldsymbol{p}}$, incomplete yet valuable databases, and other sources of knowledge under conditions of uncertainty. In our next example the space–time attribute $X_{\boldsymbol{p}}$ denotes the average daily temperature. Consider an agent's prediction that the $X_{\boldsymbol{p}}$ value at $\boldsymbol{p} =$ (San Diego, September 19, 2011) will be $\chi_{\boldsymbol{p}} = 26.3°$ with probability $P_{KB}[X_{\boldsymbol{p}} = 26.3°] = 0.6$.[9] This probability refers to the agent's assertion (based on the available knowledge base, KB) that the temperature value $\chi_{\boldsymbol{p}} = 26.3°$ has probability 0.6, rather than the standard claim that the probability of the temperature value above is 0.6. Said otherwise, since the term "probability" is used by the agent to talk about the attribute realization $\chi_{\boldsymbol{p}} = 26.3°$, it is part of the stochastic reasoning metalanguage. I will revisit the subject in Chapter 6, after we first introduce in the next section another key element of stochastic reasoning, namely, the spatiotemporal random field concept.

[9] In mathematical terms, stochastic reasoning views the temperature attribute as a spatiotemporal random field, see Section 5.3 that follows.

5.3 The Spatiotemporal Random Field Concept

Stochastic reasoning involves a variety of concepts – abstract and intuitive, formal and interpretive, epistemic and ontic, mathematical and physical. And, equally important, it involves interactions between these concepts that honor a capacity for experience, engage consciousness, and offer new ways of imagining the world. As such, the subject of stochastic reasoning is replete with theoretical issues. One of the main theoretical concepts is the *spatiotemporal random field* (*S/TRF*). Let us start with the thought process that leads to the formulation of the S/TRF as currently conceived.

5.3.1 The Possible Worlds Representation: Epicurus, Leibniz, and Voltaire

An influential school of thought promotes the study of Nature in terms of the so-called *possible worlds representation* (*PWR*). According to PWR, the agent's mental conception of Nature should involve many possible worlds (or realizations). The world that is currently observable by means of the agent's cognitive means is just one of the many possible worlds – the worlds of possibilities concerning what one may find if Isis' veil is ever lifted, metaphorically speaking.

The PWR idea can be traced back in the third and fourth centuries BC Epicurean teachings "on the plurality of worlds (*κὸσμοι*)." According to Epicurus, it is possible to propose multiple explanations of a phenomenon, each of which must agree with appearances. In a famous letter to Herodotus, Epicurus writes that, "there are infinite worlds both like and unlike this world of ours" (Konstan, 1972).[10] Gottfried Leibniz viewed the PWR as ideas in the God's mind who accordingly created the currently existing world to be "the best of all possible worlds." A well-known reference to the religious relevance of this characterization is due to François-Marie Arouet, better known as Voltaire. Voltaire (2005) used the characterization in his novel *Candide* to ridicule the theologicians' claim that divine justice was served by the great Lisbon earthquake on All Saints' Day, 1755 (over 30,000 lives were allegedly lost). In modal logic, the PWR is called modal actualism, which assumes that possible worlds exist as abstract entities that are distinguished from the actual world. Another PWR interpretation is modal realism, which assumes that the possible worlds exist just as surely as the actual world does. In Epibraimatics (see, also, Section 3.5.1), the PWR posits the existence of worlds within our mentally extended senses that must connect or relate with our own. PWR is inherent in the imaginative construction approach of human inquiry. An agent constructs an approach to reality (rather than reality per se), which relies on agent's coherent and creative imagination. In the context of the

[10] A relevant source is Lucretius' poem on Epicureanism titled *De Rerum Natura* ("On the Nature of Things"; Book 2, ll. 1023–1089).

imaginative construction approach, one uses an instrument to see a world (say, W_2) that one can never see with the naked eye (which can only see the world W_1). The action of building and using the instrument implies that the agent assumes that there indeed exists a world to be seen. The PWR realizations in connection with the real-world situation have two main features: (*a*) the realizations are consistent with the physical, practical, or logical conditions of the specified problem and (*b*) they have different probabilities of occurrence, depending on the epistemic situation of the agent. Feature *a* may be linked to different IPS kinds (Section 2.3.4), i.e., solutions that are physically, practically, or logically possible (the reader is reminded that something that is not physical is only accessible mentally). And Feature *b* may be associated with the agent's mode of thinking, worldview, system of beliefs, cognitive means, and knowledge sources.

5.3.2 Causality–Randomness Interaction

According to many historians, Aristotle was the first to combine probability with necessity (Section 4.3.3). Aristotelian insight underlies the basic idea of stochastic reasoning concerning the co-existence and interaction of randomness with causality in the quantitative description of attributes and systems that unfold *spatially* with the course of *time*. In addition, stochastic reasoning includes a group of spatiotemporal models with attractive features that reflect the epistemic fact that agents are pattern-forming creatures: they like to, have to, or do connect things. As emphasized by Gerald M. Edelman (2006: 58), brain is a selectional system that operates *prima facie* by pattern recognition. In this respect, the S/TRF model plays an important role that aims at studying the uncertain properties of a system as a whole, and connecting them to causal relations and space–time patterns. The S/TRF model is briefly reviewed below; a detailed presentation of the mathematical theory and its various applications can be found in the literature (Christakos 1991a, b, 1992; Christakos and Hristopulos 1998).

5.3.2.1 Agents Who Are Not Mute in Their Souls

Consider an in situ attribute that varies in a composite space–time domain (e.g., air pollution concentration, water level, epidemic mortality, soil property, land use, poverty level, or commodity price). In light of the PWR, the S/TRF $X_{\boldsymbol{p}} = X_{s,t}$ is represented as

$$X_{\boldsymbol{p}} \to \begin{cases} \chi_{\boldsymbol{p}}^{(1)} = (\chi_{\boldsymbol{p}_1}, \ldots, \chi_{\boldsymbol{p}_k})^{(1)} \\ \chi_{\boldsymbol{p}}^{(2)} = (\chi_{\boldsymbol{p}_1}, \ldots, \chi_{\boldsymbol{p}_k})^{(2)} \\ \qquad \vdots \\ \chi_{\boldsymbol{p}}^{(R)} = (\chi_{\boldsymbol{p}_1}, \ldots, \chi_{\boldsymbol{p}_k})^{(R)} \end{cases}; \tag{5.7}$$

i.e., $X_{\boldsymbol{p}}$ is viewed as the collection of all possible space–time distributions or realizations, $\chi_{\boldsymbol{p}}^{(j)}$ ($j = 1,\ldots, R$) at the space–time points $\boldsymbol{p} = (\boldsymbol{p}_1, \ldots, \boldsymbol{p}_k)$ of the attribute represented in terms of the S/TRF. In the random field setting, the attribute realizations $\chi_{\boldsymbol{p}}^{(j)}$ have some features that are worth noticing: (*i*) The realizations are consistent with the physical properties, uncertainty sources, and space–time variations characterizing the attribute distribution (i.e., the multiplicity of realizations makes it possible to account for uncertainty sources and, at the same time, to adequately represent the spatiotemporal variation of an attribute). (*ii*) They have the epistemic quality of corresponding to ways that are consistent with the known[11] system properties rather than to all possible ways a system could be represented in terms of formal logic. (*iii*) They have different chances of occurrence, in general; each realization has a distinct probability to occur that depends on the epistemic condition of the investigator and the underlying mechanism of the in situ phenomenon. The implication of Feature *iii* is that Eq. (5.7) could be re-written in a more informative way as follows:

$$X_{\boldsymbol{p}} \rightarrow \begin{cases} \chi_{\boldsymbol{p}}^{(1)} & \textit{with probability } P_{KB}^{(1)} \\ \chi_{\boldsymbol{p}}^{(2)} & \textit{with probability } P_{KB}^{(2)} \\ & \vdots \\ \chi_{\boldsymbol{p}}^{(R)} & \textit{with probability } P_{KB}^{(R)} \end{cases}, \tag{5.8}$$

where the subscript KB denotes the knowledge base used to construct the probability model in the stochastic reasoning setting of Section 5.2.2. According to the above perspective, the agent is in control of possibilities (S/TRF realizations), but not actualities. In other words, the control involves the agent's mind in a way that the agent could predict what was *likely* to occur, but not what *will* actually occur. In this sense, the future could potentially influence the present as much as the past. That which does not exist in one realization but exists in some other realization shares certain important characteristics with that which actually exists. To understand a phenomenon and assess the actual risks linked to it, one needs to be aware not only of the favorable scenarios but also of the usually much larger number of unfavorable scenarios that did not occur this time, but could occur the next time around.[12] To put it in a literary way, *that which probably isn't affects what is.*

It is a signature of our times that this sort of multi-thematic integrative thinking cannot be appreciated by those who promote a society with low intellectual

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[11] "Known" is here associated with human consciousness.

[12] To use a real life scenario, since there are so many conditions that need to be satisfied simultaneously for Tiberius Finamore to be the only survivor of an airplane crash, the fact that he survived makes it tempting to believe that there was another reason that made his survival highly probable a priori (say, God likes Tiberius) rather than to admit that his chances to survive were indeed extremely small (there are many possible realizations that did not favor Tiberius' survival but are ignored).

standards, and an eye only for the illusive "bottom line." It is not difficult to imagine just how startling, and even frightening, the PWR idea of an infinity of possible worlds seem to those who have been programmed to think "within the box" and only believe what they can touch. On the contrary, integrative thinking under conditions of uncertainty is the kind of stuff that can be appreciated by those individuals who are not mute in their souls. Understanding, appreciating, and implementing stochastic reasoning and random field theory require a broad and penetrating imagination rather than a dry pedantic brain, and an incisiveness of the mind rather than a formulaic thinking.

5.4 Stochastic Characterization

The mathematical S/TRF theory will be presented to the extent necessary for the purposes of this book. In stochastic reasoning terms, the description of an attribute distributed across space–time concentrates on the web of possible attribute patterns across space–time and what lies beneath them. Correspondingly, the S/TRF model of such an attribute is fully characterized by its PDF, f_{KB}, which is generally defined as

$$\boldsymbol{P}_{KB}[\Lambda(\boldsymbol{\chi}_{\boldsymbol{p}},\ \boldsymbol{d\chi}_{\boldsymbol{p}})] = f_{KB}(\boldsymbol{\chi}_{\boldsymbol{p}})\,\boldsymbol{d\chi}_{\boldsymbol{p}}, \tag{5.9}$$

where $\boldsymbol{d\chi}_{\boldsymbol{p}} = \prod_{i=1}^{k} \boldsymbol{d\chi}_{\boldsymbol{p}_i}$ and $\Lambda(\boldsymbol{\chi}_{\boldsymbol{p}},\ \boldsymbol{d\chi}_{\boldsymbol{p}}) = (\chi_{\boldsymbol{p}_i} \leqslant X_{\boldsymbol{p}_i} \leqslant \chi_{\boldsymbol{p}_i} + d\chi_{\boldsymbol{p}_i}; i = 1, ..., k)$ for all k. When k=1, Eq. (5.9) reduces to the special case of a *univariate* PDF; and when k>1, the term *multivariate* PDF is used, instead. While the univariate PDFs define the S/TRF at a local scale, the multivariate PDF characterizes it at a global scale. Technically, $f_{KB}(\boldsymbol{\chi}_{\boldsymbol{p}})\,\boldsymbol{d\chi}_{\boldsymbol{p}}$ could be replaced by the more general $\boldsymbol{d}F_{KB}(\boldsymbol{\chi}_{\boldsymbol{p}})$, where $F_{KB}(\boldsymbol{\chi}_{\boldsymbol{p}})$ is the corresponding CDF, but at the moment continuous and differentiable CDF are assumed, in which case Eq. (5.9) is sufficient for the goals of our investigation.

5.4.1 The Holy Grail

Equation (5.9) involves both the *content* of the investigator's thinking process and the in situ *context* of the attribute. Naturally, the construction of f_{KB} on the basis of the available KBs is a critical process with epistemic, cognitive, and psychological characteristics. It is, hence, important that the investigator uses the appropriate f_{KB} interpretation, be aware of the problem space within which the interpretation is valid, and carefully implement content-sensitive logic norms (Section 6.1) that maintain consistency among the KB elements. This being the case, it should come as no surprise that the f_{KB} is considered the *Holy Grail*, so to speak, of S/TRF analysis.

By means of Eq. (5.9), the f_{KB} assigns numerical probabilities to the $X_{\boldsymbol{p}}$ realizations that evolve between multiple space–time points, see Eq. (5.8). The f_{KB} describes the comparative likelihoods of the various realizations and not the certain occurrence of a specific realization. Accordingly, the PDF unit is probability per realization unit. This may be the time to remind the readers that one should not underestimate the importance of notation. The same entity may be represented using different symbols, depending on the context and the emphasis one wants to assign to the relevant variables. A probability may be denoted as P_X if it is contextually significant to denote that this is the probability function of the S/TRF $X_{\boldsymbol{p}}$; or by P_{KB} if one needs to emphasize that the probability function has been constructed on the basis of a specified KB and that underlying it is a particular methodology and worldview. Similarly, a PDF may be simply denoted as f_{KB}; as $f_{KB}(\chi_{\boldsymbol{p}})$ if the goal is to emphasize the $X_{\boldsymbol{p}}$ realizations; or as $f_{X,\boldsymbol{p}}$, $\boldsymbol{p} = (\boldsymbol{p}_1, \ldots, \boldsymbol{p}_k)$ if it is necessary to indicate that the PDF is a function of the space–time domain. Also, while $f_{X,\boldsymbol{p}} = f_X(\boldsymbol{p}_1, \ldots, \boldsymbol{p}_k)$ denotes a multivariate PDF, $f_{X,\boldsymbol{p}_i} = f_X(\boldsymbol{p}_i)$, i=1,..., k, denotes a set of univariate PDFs.

5.4.2 Multiple Conceptual Layers

In view of Eq. (5.9), multiple realizations of the attribute under consideration are possible *before the event* (i.e., before the actual attribute distribution reveals itself). In the investigator's mind, the attribute could exhibit one of several possible realizations, until it is observed or measured. Attribute's probability of exhibiting any particular realization is a measure of how likely it is that the attribute exhibits this realization when it is observed or measured given the agent's epistemic condition. Plainly speaking, the attribute realizations exist as probabilities (or potentialities), becoming certain only as they are observed or measured. Observation of an attribute realization by a conscious investigator (using the cognitive means available, natural or technical) transfers its state from one of uncertainty into one of definiteness. But this is not the whole story. Just like an onion with its many layers, each of which is attached to the one beneath it, the S/TRF has several conceptual layers, each one possessing some salient features: (*a*) It assumes the existence of a composite space–time manifold, i.e., space and time constitute an integrated whole than two separate entities; (*b*) it incorporates spatiotemporal interdependencies and cross-correlations of the attribute distribution expressed by the laws of change; (*c*) it is of immediate relevance to models that are mathematically rigorous and tractable and, at the same time, logically or physically plausible; and (*d*) it is capable of generating informative images enabling the determination of important characteristics of the attribute distribution across space–time. When representing an attribute in terms of an S/TRF, the investigator assigns to it a random character and an equally important structural character. Thus, a realization is allowed only if it is consistent with the KBs about the situ attribute and the investigator's logical reasoning. Clearly, not all S/TRF realizations are equally probable. Depending on the underlying mechanisms, some realizations are more probable than others, and this is reflected in the PDF model of the S/TRF.

It is always enlightening to think in a literary way about a mathematical concept, and view its properties in the light of historical or cultural situations. Accordingly, let us consider two instructive yet very different examples representing extreme cases of parallel worlds. Around 250 BC, King Ptolemy Philadelphus sent 72 Hebrew scholars (six from each tribe of Israel) to translate *Septuagint* (Hebrew Scriptures) into Greek and add them to the Alexandria library. He secluded these men on the island of Phares, where each worked separately on his own translation, without consultation with one another. According to legend, when they came together to compare their work, the 72 copies proved to be identical. This is an extreme case, one must admit, in which all parallel worlds (realizations) reduce to a single world with probability of occurrence equal to one (certainty or determinism). If the *Septuagint* example represents a rather extreme case of "perfectly consistent parallel worlds," the opposite is the case of the second example drawn from contemporary European politics: politicians with radically postmodern features gained fame for their political style based on a set of parallel worlds that often contradicted each other, involved logically inconsistent accounts of events, and had no relation whatsoever to evidential truth and objective facts. These politicians are characterized by their Orwellian twists of the truth. One of their "gifts" is their ability to comfortably generate contradicting worlds (account of events): one world for their voters, another one for lobby interests, another one for activist organizations, and yet another one for foreign leaders.[13] Unlike the parallel worlds of contemporary politics, the S/TRF worlds of scientific inquiry share a common structure that is determined by what is known about the phenomenon and by the rigorous rules of internal consistency and truth searching.

5.4.3 Robert Frost's Moment of Choice, and the Case of Paradoxes

In sum, because it can investigate the different forms of space–time dependency allowed by the available knowledge, the $X_{\boldsymbol{p}}$ model is able to generate multiple permissible realizations and provide assessments of their likelihood of occurrence. Technically, by combining $f_{X;\boldsymbol{p}}$ with some kind of efficient Monte Carlo simulator, one can comfortably generate numerous $X_{\boldsymbol{p}}$-realizations and look at certain of their prevalent features, thus gaining additional intuition to that obtained by studying the analytical expression of $f_{X;\boldsymbol{p}}$, when available.

[13] Europe's ruling elites (cliques would be nearer the mark) are engaged in policies that go so radically against the wishes of ordinary citizens that the rift is widening between the people and the governing elite.

5.4.3.1 The Road Not Taken

In Section 1.1.3 we suggested that just as poetry does, creative modeling feeds one's imagination with possibilities. Surely, the consideration of all possible realizations provided by the S/TRF model can be very informative and insightful in the investigator's effort to assess both how much one knows and how much one does not know about the in situ situation. But if one needs to make a choice, which realization one should select and why? This is a reasonable question that cannot be answered using technical tools alone, although it can be aided considerably using substantive means (e.g., understanding the underlying physical mechanisms, expertise with the in situ conditions, and logical considerations). A poem, on the other hand, can stir all of the senses, which means that resort to the literary way of expressing one's thinking is intriguing and often conceptually motivating. In his poem *The Road Not Taken*, Robert Frost challenges the reader's imagination with the dilemma:

> I shall be telling this with a sigh
> Somewhere ages and ages hence:
> Two roads diverged in a wood, and I–
> I took the one less traveled by,
> And that has made all the difference.

One road is well traveled – like a high probability random field realization. And another one is less traveled – like a low probability realization. What is then the optimal choice? This depends, the readers may comment, on the agent's grasp of the in situ situation, personal conviction, creative imagination, and well-thought objectives. Selecting the most probable realization may seem a rational decision, but is it always so? The highly improbable realization, when it occurs, can be very consequential. Indeed, as deadly worldwide epidemics and financial disasters have shown, it does not matter how rare an event is, if its occurrence is too costly to bear.

In any case, the take home message is that choices are inevitable. And just like in Frost's poem, one will not know with certainty what the specific choice of a possibility actually implies until one has lived it, until the possibility has been observed and its former probability obtains its maximum value. *Ex animo*, isn't this state of one constantly facing crucial choices and new challenges the essence of an uncertain life?

5.4.3.2 The Case of Apparent Paradoxes

Admittedly, one may get the impression that there are a few conceptual paradoxes linked to the stochastic reasoning implicit in S/TRF analysis. An apparent paradox is that the S/TRF gives answers in terms of possibilities, all considered by the investigator at the same time, which seems unreal. However, one should not forget that we already have a very good non-technical word for the mixture of possibilities that co-exist at the same time: we call it *future*, which is imperfectly known to humans due to their incomplete knowledge about the in situ phenomenon.[14] Another apparent paradox is that the S/TRF seems to imply that there is an instant awareness between the attribute values across space–time, which seems strange (especially if one is used to work with independently distributed variables). But, this awareness is in the investigator's mind (epistemic entity), and not in the actual phenomenon (unknown ontic entity). *A posse ad esse*, from possibility to actuality, the S/TRF model allows for the observation effect: when an observation takes place at a specific space–time point, awareness is expressed by a reduced set of possibilities at all points according to the model (in technical terms, this is sometimes called conditional S/TRF simulation).

5.5 About Laws, Power Holders, and Rembrandt's Paintings

"Laws? Like who the f*** cares?" was the attitude of the people participating in CIA programs in the early 2000s, according to a senior CIA official (Horton 2008: 50).[15] However, as any rational human being (who is not blinded by the extremist dogmas and the superiority complexes of clerkdoms and power holders) knows, laws constitute an important component of organized social life and, as far as this book is concerned, scientific life too. In the latter case, the natural laws are essential ingredients of real-world IPS. As David Novak (2008: 177) puts it, "Human cultures can only avoid the question of natural law when they identify themselves alone with humankind per se and regard all outsiders as devoid of humanity." The following is a famous passage from John Donne's 1624 prose *Meditation XVII*:

> No man is an island, entire of itself; every man is a piece of the continent, a part of the main. If a clod be washed away by the sea, Europe is the less, as well as if a promontory were, as well as if a manor of thy friend's or of thine own were. Any man's death diminishes me, because I am involved in mankind, and therefore never send to know for whom the bells tolls; it tolls for thee.

These lines reflect powerful ideas of the Renaissance era about the interconnectedness of human experience. This interconnectedness extends to any entity (attribute, process, phenomenon, etc.) within a system, since no entity is isolated from the other entities of the system. The breaking of the isolation and the simultaneous formation of interconnectedness is made possible by means of natural laws. For Xie Liu (2003) even literary works are created according to the natural laws of the universe. All entities depicted in these works (people, animals, trees, mountains, etc.) are in accord with the rational principle expressed in words and

[14] On the contrary, determinism describes events as inevitable, effectively depriving humans of a future.

[15] Remarkably, a similar attitude toward human laws was exhibited in President Lyndon Johnson's blast to a European ambassador in the 1960s (Wittner 1982: 303): "F*** your Parliament and your Constitution . . . If your Prime Minister gives me talk about Democracy, Parliament and Constitution, he, his Parliament and his Constitution may not last very long."

things with their specific characteristics. At this point, it would be useful to consider yet another classification of the laws used in scientific applications. In Epibraimatics, the reader is reminded, natural laws are linked to the agent's capacity of rational reason to reflect upon the conditions and content of in situ experience.

5.5.1 Deterministic Laws

In the case of deterministic causal laws, the value $\chi_{\boldsymbol{p}}$ of an attribute $X_{\boldsymbol{p}}$ can be calculated at any space–time point $\boldsymbol{p} = (\boldsymbol{s}, t)$, if the relevant boundary and/or initial conditions (BIC) X_0 and coefficients a_i ($i = 1,2...,k$) are known. In a symbolic form

$$M_X(a_i, X_0, X_{\boldsymbol{p}}) = 0, \tag{5.10}$$

where M_X denotes a model derived on the basis of a scientific theory. Law (5.10) represents persistent and reproduced features of natural phenomena, whereas X_0 represents individual, contingent, and irreproducible cases of the law's action, in general. Using Newton's laws and the necessary BIC, e.g., one could, in principle, calculate the position and velocity of an object at any time instant. Although scientific laws of the form suggested by Eq. (5.10) are assumed to be generally applicable, they may be of different levels of fundamentality (e.g., Darcy's law is of a lower level than that of Newton's laws). In addition, some of them are observable laws (macroscopic level), whereas some others are not (subatomic level). Certain laws specify the actual mechanism underlying a phenomenon, whereas other laws are purely phenomenological (Table 1.12).

5.5.2 Statistical Laws

In the case of a statistical law, the attribute value $\chi_{\boldsymbol{p}}$ cannot be calculated with certainty at any space–time point $\boldsymbol{p}$, but only its frequency of occurrence

$$F_{X;\boldsymbol{p}}(\chi_{\boldsymbol{p}}) = n_{\chi_p} N^{-1} \tag{5.11}$$

can be calculated experimentally on the basis of past data (N is the total number of data, and n_{χ_p} is the number of times the value $\chi_{\boldsymbol{p}}$ turned out). When tossing a die, e.g., one cannot predict whether "heads" or "tails" will come up. But, on the basis of past experiments with the die, one can say that among any number of throws, it is expected that about half will turn up "heads." There is no causality present in the statistical law above (say, in the form of the Newtonian laws characterizing the motion of an object such as the die). Methodologically, statistical analysis of this sort is based on pure induction, which means that it suffers from many of the problems associated with this sort of reasoning (Section 5.2.1).

5.5.3 Stochastic Laws

Now comes the interesting part, as far as stochastic reasoning is concerned. A stochastic law obeyed by the S/TRF $X_{\boldsymbol{p}}$ has the same symbolic form as Eq. (5.10),

$$M_X(a_i, X_0, X_{\boldsymbol{p}}) = 0, \tag{5.12}$$

with one key difference: the BIC X_0 and the coefficients a_i ($i = 1,2,...,k$) are now random fields.[16] The (uncertain) causality between the random fields a_i, X_0 and $X_{\boldsymbol{p}}$ is expressed by the stochastic formulation (5.12). In this setting, a natural law can be put in the form of stochastic equations by admitting that some or all of its constituents are not perfectly known and, hence, they must be represented as random fields. The upshot is clear: while Eq. (5.10) is a law of necessity and Eq. (5.11) is a law of chance, Eq. (5.12) is a law that expresses the dialectic*s* of randomness and necessity. In this sense, a stochastic law is closer to a natural law than to a purely statistical one. Readers have already acquainted themselves with the species growth law of Section 4.3.3, in which the attribute was represented by the stochastic differential equation

$$\tfrac{d}{dt}X_{\boldsymbol{p}} - aX_{\boldsymbol{p}} = 0, \tag{5.13}$$

where a is a known physical coefficient. The attribute's X_0 refers to the point $(\boldsymbol{s}, 0)$ and is random. As a second example consider a quantum system governed by the stochastic Schrödinger law,

$$i\hbar\tfrac{\partial}{\partial t}\psi_{\boldsymbol{p}} - \hat{H}\psi_{\boldsymbol{p}} = 0, \tag{5.14}$$

where i here denotes the imaginary unit, $\hbar$ is the reduced Planck constant, $\hat{H}$ is the Hamiltonian operator, and $\psi_{\boldsymbol{p}}$ is the wave function.[17] The readers may be reminded that, although Schrödinger's equation is fundamentally stochastic expressing quantum uncertainty, his thinking was not always so, as he once declared in no uncertain words that, "It has *never* happened that a woman has slept with me and did not wish, as a consequence, to live with me all her life" (Mlodinow 2001: 221).

The method that derives the equation of the corresponding PDFs from the stochastic natural law (5.12) is conceptually straightforward, but its practical

[16] Note that since Eq. (5.10) is deterministic, the solution $X_{\boldsymbol{p}} = \chi_{\boldsymbol{p}}$ has probability 1. This is not the case, however, with Eq. (5.12).

[17] A detailed discussion of the underlying physics is beyond the scope of the present discussion, but the interested reader is referred to the numerous volumes on quantum mechanics (e.g., Messiah 1999).

implementation is often not an easy task. In a symbolic form, the stochastic law that $f_{X;\boldsymbol{p}}$ satisfies is generally represented by

$$M_f(f_{a_i}, f_{X;0}, f_{X;\boldsymbol{p}}) = 0, \tag{5.15}$$

where f_{a_i} and $f_{X;0}$ are the PDFs of the random coefficients a_i ($i = 1,2,...,k$) and the BIC (X_0), respectively. In more involved physical situations, it is also possible that the stochastic law (5.15) includes the joint PDF of a_i, X_0, and $X_{\boldsymbol{p}}$. Remarkably, while the (uncertain) causality between the random fields a_i, X_0, and $X_{\boldsymbol{p}}$ is expressed by the stochastic formulation (5.12), the (deterministic) causality (5.15) does not connect the attribute values themselves, but their PDFs. A more detailed analysis of the equations governing the PDFs will be given in Section 5.6.2. Epibraimatics focuses primarily on Eq. (5.12)–(5.15), since this is the formulation that best expresses the original ideas of Aristotle, Kant, Boltzmann, Schrödinger, and others concerning the fundamental connection of randomness and causality. Moreover, these equations are in agreement with the fundamental viewpoint that data are not merely numbers. Instead, they convey a message from the natural phenomenon they represent in the same way the paintings of Rembrandt convey a message from seventeenth-century Europe. From the stochastic law (5.15), one can estimate any attribute value $\chi_{\boldsymbol{p}}$ one wishes. The term "estimate" is important here: Unlike the case of the deterministic causal law (5.10), the stochastic solution $\chi_{\boldsymbol{p}}$ does not necessarily have probability 1. Instead, the solution has a specified probability of occurrence (between 0 and 1) with its associated estimation accuracy. To put it in different words, this sort of estimation may be seen as a process by means of which the probabilities turn into uncertain possibilities. In which case Judea Pearl (2010: 1) justifiably complains that certain fields seem to ignore the knowledge provided by science-based laws generating the data distributions: "Questions [in health, social and behavioral sciences] require some knowledge of the data-generating process, and cannot be computed from the data alone ... Remarkably, although much of the conceptual framework and algorithmic tools needed for tackling such problems are now well established, they are not known to many of the researchers who could put them into practical use."

5.5.4 Comparative Summary

Before leaving this section, in Table 5.5 I summarize some of the salient differences between the three types of laws considered above. The readers may recall that in the case of the deterministic law, one observes the coefficients and BIC, and then derives attribute values $\chi_{\boldsymbol{p}}$ at any $\boldsymbol{p}$. In the case of the stochastic law the corresponding entities are random fields, which means that the law represents the co-existence of randomness and causality (the law can be conditioned by data, whenever available). Given the $f_{X;0}$ and f_{a_i}, the PDF law (5.15) derives $f_{X;\boldsymbol{p}}$ across space–time. In the case of the statistical law, on the other hand, based on a certain

Table 5.5 Main characteristics of deterministic, statistical, and stochastic laws

	Entities related by law	Description of what is observed or observable	Symbolic pattern describing entities
Deterministic law:	Attribute values linked by causality	Law coefficients, BIC	Science-based conceptual scheme
Statistical law:	No causality present	Dataset	Statement about facts
Stochastic law:	Attribute values linked by (uncertain) causality PDFs linked by causality	Random law coefficients, BIC PDFs of coefficients, BIC Uncertain dataset	Science-based conceptual scheme

number of χ_p observations one merely derives a frequency law of the attribute that is assumed valid, in general. Having as a common origin a scientific theory, the deterministic and stochastic laws are science-based conceptual schemes, whereas the statistical law is merely a statement about observed facts.

5.6 Constructing Multivariate PDF Models

Since in stochastic reasoning one must learn to think and act in terms of PDFs (distributed across space–time and following laws of Nature) rather than single attribute values, it makes sense to develop effective ways to construct these PDF in praxis. Like Percival, the Round Table Knight who needed to grow mentally before he could locate the Holy Grail, stochastic theorists need to constantly improve their epistemic conditions in order to be able to credibly construct the complete multivariate PDFs across space–time. Since this turns out to be a difficult endeavor in real-world situations, it is not surprising that a number of "shortcuts" are often used in practice. This section examines certain well-known approaches to construct a PDF model. To paint with a broad brush, a basic classification of these approaches is as follows: (*i*) *Formal* PDF model construction, which includes models that are speculative, analytically tractable, or ready-made. (*ii*) *Substantive* PDF model construction, which includes models having a firm basis in reality (determined on the basis of scientific knowledge and evidential experience), taking into account the contentual and contextual domain of the in situ situation.

5.6.1 Formal Construction: Copulas and Factoras

First, we will study speculative PDF models that are either ready-made or possess analytically tractable properties. As to the merits of formally constructed PDFs, it must be said at the very outset that the consequences of using the wrong PDF in real-world situations can be more severe than those displayed by the PDF itself.

5.6.1.1 Ready-Made and Tractable PDF Models

There is a list of PDF models that have been derived using formal analytical techniques. The most famous example, of course, is the multivariate *Gaussian* (*normal*) PDF model

$$f_{X;\boldsymbol{p}} = [(2\pi)^k |C|]^{-1/2} e^{-\frac{1}{2}\sum_{i,j=1}^{k} c_{ij}(\chi_{\boldsymbol{p}_i}-m_i)(\chi_{\boldsymbol{p}_j}-m_j)}, \tag{5.16}$$

with parameters m_i and m_j (i,j=1,...,k); $|C|$ is the determinant of a positive-definite matrix C with elements c_{ij}. The PDF (5.16) has many convenient properties that are described in the relevant literature (Tong 1990). Despite its attractive properties, many experts argue that the multivariate Gaussian PDF is unequipped to answer questions about the occurrence of rare but catastrophic events (linked to natural disasters, financial crises etc.). Beyond that, often there is no substantive justification why to prefer this type of "well behaved" PDF to those models that emphasize the possibility of "catastrophic" events.

Other well-known analytically tractable ready-made multivariate PDFs include the *Student*, *exponential*, *lognormal*, *elliptical*, *Cauchy*, *beta*, *gamma*, *logistic*, *Liouville*, and *Pareto* models (a detailed presentation of ready-made multivariate distributions can be found in Kotz et al. 2000 and Genton 2004). A basic feature of many of these multivariate PDFs is that the corresponding univariate PDF are of the same kind (e.g., if the multivariate PDF is Gaussian, so is the univariate). As the readers are aware, the inverse is often not true. That is, a univariate PDF (say, Gaussian) may be associated with a multivariate PDF of a different kind (non-Gaussian).[18] These facts can cause serious problems in many applications in which one deals with non-Gaussian fields $X_{\boldsymbol{p}}$ that have different kinds of univariate $f_{X,\boldsymbol{p}_i}$ (e.g., $f_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ is non-Gaussian, whereas $f_{X;\boldsymbol{p}_1}$ is Gaussian and $f_{X;\boldsymbol{p}_2}$ is gamma). In such cases, a key question is how to extend the univariate PDFs that are usually available in practice to a multivariate PDF that fits the attribute of interest across space–time. This kind of problems constitutes a prime reason for the systematic development of the copula- and factora-based representations of a multivariate PDF (Section 5.6.1.2 and 5.6.1.3).

There are also PDF models that are assumed to have particularly tractable analytical forms. A rather trivial case of such a multivariate model is the PDF with full *stochastic independence*:[19]

$$f_{X,\boldsymbol{p}} = f_X(\boldsymbol{p}_1, \ldots, \boldsymbol{p}_k) = \prod_{i=1}^{k} f_{X,\boldsymbol{p}_i} \tag{5.17}$$

[18] In this sense, the multivariate PDF behaves like the Holy Grail of the legends of the questing king Arthur's knights, which assumed different shapes, forms, origins, and interpretations.

[19] The reader is reminded that stochastic (or probabilistic) independence is different from logical independence (Table 4.2).

for all k. This model essentially describes phenomena that do not transmit knowledge across space–time, i.e. one's knowledge of the attribute's state at point $\boldsymbol{p}_i$ does not affect one's knowledge of the state at point $\boldsymbol{p}_j$. Although mathematically convenient, model (5.17) is of rather limited use in real-world situations. A more interesting model is that of *partial* stochastic independence (e.g. (5.17) holds for $k=2$, but not for $k=3$, etc.). Multivariate PDFs can be derived in cases when a specific relationship is known to exist between the random-field realizations. An interesting yet rather limited model is the PDF with *spherical symmetry*, simply written as (Blokh 1960)

$$f_{X,\boldsymbol{p}} = f_X(\boldsymbol{p}_1, ..., \boldsymbol{p}_k) = g(\xi), \tag{5.18}$$

where $\xi = (\sum_{i=1}^{k} \chi_{\boldsymbol{p}_i}^2)^{1/2}$. This PDF is an even function that is symmetric with respect to $\chi_{\boldsymbol{p}_i}$. All univariate PDFs are the same, $f_{X,\boldsymbol{p}_i} = f_X(\chi)$, $i = 1,..., k$. The multivariate PDF (5.18) is determined from the univariate PDF via the integral representation

$$f_{X,\boldsymbol{p}_i}(\chi) = \frac{2\pi^{(k-1)/2}}{\Gamma(\frac{k-1}{2})} \int_0^\infty d\xi\, \xi^{k-2} g((\chi^2 + \xi^2)^{1/2}), \tag{5.19}$$

where Γ is the gamma function. The class of multivariate $f_{X,\boldsymbol{p}} = g(\xi)$ is obtained by assuming different univariate PDF $f_{X,\boldsymbol{p}_i}$ and then inverting Eq. (5.19). In the case of stochastic independence, $f_{X,\boldsymbol{p}} = \prod_{i=1}^{k} f_{X,\boldsymbol{p}_i} = g(\xi)$, one finds the PDF model $f_{X,\boldsymbol{p}_i} = c_0 e^{c_1 \chi^2}$ (c_0, c_1 are suitable coefficients), which is the Gaussian case. In some other situations, the multivariate PDF $f_{X;\boldsymbol{p}}$ can be expressed in terms of its univariate PDFs $f_{X;\boldsymbol{p}_i}$ ($i = 1,...,k$) and a set of functions of $\chi_{\boldsymbol{p}_i}$. This could be of considerable interest, because often one has good knowledge of $f_{X,\boldsymbol{p}_i}$ and seeks to construct $f_{X;\boldsymbol{p}}$ that is physically meaningful, and its parameters can be estimated in practice. Two noteworthy cases are considered next: Copulas and factoras.

5.6.1.2 Copula-Based PDF Models

Under certain technical assumptions, a multivariate PDF can be written in terms of the so-called *copula* (Sklar 1959; Genest and Rivest 1993; Nelsen 1999),

$$C_{X;\{\boldsymbol{p}_i\}} = C_X(F_{X;\boldsymbol{p}_1}, ..., F_{X;\boldsymbol{p}_k}) = P[F_{X;\boldsymbol{p}_1} \leqslant \upsilon_{\boldsymbol{p}_1}, ..., \; F_{X;\boldsymbol{p}_k} \leqslant \upsilon_{\boldsymbol{p}_k}], \tag{5.20}$$

where $F_{X;\boldsymbol{p}_i}$ are univariate CDF, and $\upsilon_{\boldsymbol{p}_i}$ are realizations of $U_{\boldsymbol{p}_i} = F_{X;\boldsymbol{p}_i}^{-1} \sim U(0,1)$, $i = 1,..., k$. Any distribution function with support on $[0,1]^k$ and uniform marginals has been termed a copula (Mikosch 2006a: 5). The corresponding copula density is defined by $\varsigma_{X;\{\boldsymbol{p}_i\}} \boldsymbol{d\upsilon} = \boldsymbol{d}C_{X;\{\boldsymbol{p}_i\}}$ (assuming copula continuity and differentiability). The $f_{X,\boldsymbol{p}}$ is reformulated in terms of its univariate PDF and the copula density as

$$f_{X;\boldsymbol{p}} = \left[\prod_{i=1}^{k} f_{X;\boldsymbol{p}_i}\right] \varsigma_{X;\{\boldsymbol{p}_i\}}. \tag{5.21}$$

Equation (5.21) basically decomposes the multivariate PDF ($f_{X,\boldsymbol{p}}$) into the product of the univariate densities ($f_{X;\boldsymbol{p}_i}$) and the multivariate copula density ($\varsigma_{X;\{\boldsymbol{p}_i\}}$) that expresses a certain form of interaction between univariate PDFs. Copula families with useful properties include the elliptic and the Archimedian ones (Genest and Rivest 1993).

As is the case with all technical apparatuses, the copula technology has its *pros* and *cons*. Basically, copula is yet another tool to estimate multivariate non-Gaussian PDFs, which is suitable for some applications, but not for some others (Joe 2006). Under certain conditions, copulas yield useful parametric descriptions of multivariate non-Gaussian fields (Scholzel and Friederichs 2008). According to Andras Bardossy (2006), a copula can express whether the corresponding spatial dependence changes for different attribute quantiles (high values may exhibit a strong spatial dependence, whereas low values a weak dependence) – although the situation is more difficult or even impossible for copulas to handle when multivariate (higher than second-order) copulas are considered. Copulas are scale-invariant in the sense that the copula of $Z_{\boldsymbol{p}} = \phi(X_{\boldsymbol{p}})$ is equal to the copula of $X_{\boldsymbol{p}}$ if $\phi(\cdot)$ is a strictly monotonic function. On the other hand, one should keep in mind that the copula technology mainly applies to continuous-valued attributes so that the marginals are uniform according to the probability integral transform theorem. No general approach exists to construct the most appropriate copula for an attribute, whereas the choice of a copula family for an in situ problem is often based not on substantive reasoning, but on mathematical convenience (Mikosch 2006a, b). If construction methods are available for componentwise maxima, no unique approaches can be established for a set of attributes that are not all extremes. This is also the case of univariate analysis, where distribution functions are usually chosen on the basis of theoretical observations and goodness-of-fit criteria. Direct interpretation of the copula alone does not offer insight about the complete stochastic nature of the attribute and there is no dependence separately from the marginals. Also, copulas do not solve satisfactorily the dimensionality problem (Scholzel and Friederichs 2008). Interpretive issues concerning the copulas' in situ applications emerge too. There are many real-world attributes that are not continuous-valued but rather discrete- or mixed-valued (e.g., daily rainfall), which means that the integral transform theorem (on which the copula technology of continuous variables relies) cannot be implemented, since the $F_{X;\boldsymbol{p}_i}$ are no longer uniformly distributed in the interval (0,1), thus giving rise to so-called unidentifiability issues (Genest and Nešlehová 2007). In this respect, although copulas can be used in simulation and robustness studies, they have to be used with caution because some properties do not hold in the discrete case. Applying copula models to datasets that do not satisfy the necessary assumptions, or disregarding proper inferential procedures, is like "the modeller telling Nature what to do," which can lead to unsatisfactory results. Also, experts have linked the extensive use of Gaussian copulas in finance with the 2008 worldwide meltdown (Salmon 2009).

This is a widely publicized case in which the model (Gaussian copulas) provided a poor representation of reality (financial markets), which also showed that analysts often use copulas without a correct inferential procedure. Attracted by the possibility to select arbitrary marginals, they sometimes forget that a suitable copula should be chosen as well as marginals. In other words, assuming a priori a Gaussian copula is like assuming Gaussian marginals without any theoretical reason or empirical evidence.

5.6.1.3 Factora-Based PDF Models

The factora technology has its origins in the Gaussian tetrachoric series expansion of Karl Pearson (1901). Although the factora PDF is apparently an older concept than the copula PDF, both concepts share some common features. The class of factora PDFs extends Pearson's original insight in a non-Gaussian random field context, leading to the class of *factorable* S/TRF (Christakos 1986, 1989, 1992). Let $\theta(\chi_{\boldsymbol{p}})$, $\chi_{\boldsymbol{p}} = (\chi_{\boldsymbol{p}_1}, \ldots, \chi_{\boldsymbol{p}_k})$, be a multivariate function of $L_2(R^k, \prod_{i=1}^{k} f_{X;\boldsymbol{p}_i})$, $r_k = \int \boldsymbol{d\chi_p} \prod_{i=1}^{k} f_{X;\boldsymbol{p}_i} \theta^2(\boldsymbol{\chi_p}) < \infty$, and let $\varpi_{j_i}(\chi_{\boldsymbol{p}_i})$ be sets of complete polynomials of degree $j = 0,1\ldots$ in $L_2(R^1, f_{X;\boldsymbol{p}_i})$ that are orthogonal with respect to $f_{X;\boldsymbol{p}_i}$. Then, one can write

$$\theta(\chi_{\boldsymbol{p}}) = [\prod_{i=1}^{k} \sum_{j_i=0}^{\infty}](\theta_{j_1\ldots j_k} \prod_{i=1}^{k} \varpi_{j_i}(\chi_{p_i})) = \theta_{X;\{\boldsymbol{p}_i\}}, \tag{5.22}$$

where the $\theta_{X;\{\boldsymbol{p}_i\}} = \theta\Big(\varpi_{j_i}(\chi_{\boldsymbol{p}_i}), i = 1, \ldots, k; j_i = 0, 1 \ldots\Big)$ is called a *factora*, and the corresponding completeness relationship is $[\prod_{i=1}^{k} \sum_{j_i=0}^{\infty}]\, \theta_{j_1\ldots j_k}^2 = r_k$ (which assures that the series expansions converge). Accordingly, the multivariate PDF is expressed as

$$f_{X;\boldsymbol{p}} = [\prod_{i=1}^{k} f_{X;\boldsymbol{p}_i}]\, \theta_{X;\{\boldsymbol{p}_i\}}, \tag{5.23}$$

which decomposes the modeling of the multivariate PDF ($f_{X,\boldsymbol{p}}$) into the product of the univariate (non-uniform, in general) densities ($f_{X;\boldsymbol{p}_i}$) and the factoras ($\theta_{X;\{\boldsymbol{p}_i\}}$) that express interactions between univariate functions of $\chi_{\boldsymbol{p}_i}$. This is an advantage of the way factoras are defined over that of copulas. Also, the factoras may offer a measure of the deviation of the multivariate PDF from the product of the univariate PDFs. An S/TRF $X_{\boldsymbol{p}}$ that satisfies Eq. (5.23) is called a factorable S/TRF (of order k).

For illustration purposes, in the bivariate case Eq. (5.23) can be reduced to

$$f_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = f_{X;\boldsymbol{p}_1} f_{X;\boldsymbol{p}_2} \sum_{j=0}^{\infty} \theta_j \varpi_j(\chi_{\boldsymbol{p}_1}) \varpi_j(\chi_{\boldsymbol{p}_2}), \tag{5.24}$$

for all $\boldsymbol{p}_1$, $\boldsymbol{p}_2$. In this case, $\theta_0 = 1$, $\theta_1 = \rho_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ is the correlation coefficient and $\theta_j \delta_{jj'} = \overline{\varpi_j(\chi_{\boldsymbol{p}_1}) \varpi_{j'}(\chi_{\boldsymbol{p}_2})}$, with $\varpi_0(\chi_{\boldsymbol{p}_i}) = 1$ and $\varpi_1(\chi_{\boldsymbol{p}_i}) = (\chi_{\boldsymbol{p}_i} - \overline{X_{\boldsymbol{p}_i}})\, \sigma_{\boldsymbol{p}_i}^{-1}$ for all space–time points $\boldsymbol{p}_i$. In (5.24), knowledge of lower order statistics is linked to the first terms of the series, whereas that of higher order statistics is linked to later terms of the series. A key step is to calculate ϖ_j that are orthogonal to a univariate PDF. There exist several methods for this purpose, where ϖ_j include Hermite, Laguerre, Generalized Laguerre, Legendre, Gegenbauer, Jacobi, and Stieltjes-Wigert polynomials.[20] To call a spade a spade, the main challenge presented by the factora formulation is how to define factoras $\theta_{X;\{\boldsymbol{p}_i\}}$ with the prescribed mathematical properties and associated complete sets of orthogonal polynomials (the difficulty increases with $k > 2$. A widely applicable method is based on the formula (Jackson 1941), $\varpi_j(\chi_{\boldsymbol{p}_i}) = f_{X;\boldsymbol{p}_i}^{-1} \frac{d^j}{d\chi_{\boldsymbol{p}_i}^j}[\upsilon(\chi_{\boldsymbol{p}_i})^j f_{X;\boldsymbol{p}_i}]$, where $\upsilon(\chi_{\boldsymbol{p}_i})$ is a function that satisfies specific conditions. This formula has been used to find polynomials for a wide range of continuous univariate PDF, including the Gaussian, exponential, and Pearson (Type I). For illustration, if $f_{X;\boldsymbol{p}_i} = \frac{1}{\sqrt{2\pi}} e^{\chi_{\boldsymbol{p}_i}^2/2}$ $(-\infty \leqslant \chi_{\boldsymbol{p}_i} \leqslant \infty)$, the bivariate PDF is $f_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = f_{X;\boldsymbol{p}_1} f_{X;\boldsymbol{p}_2}\, \theta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = f_{X;\boldsymbol{p}_1} f_{X;\boldsymbol{p}_2} \sum_{j=0}^{\infty} \rho_X^{a(j)} H_{a(j)}(\chi_{\boldsymbol{p}_1}) H_{a(j)}(\chi_{\boldsymbol{p}_2})$, H are Hermite polynomials. For $a(j) = j$, the $f_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ is bivariate Gaussian; but for $a(j) = 2j$, the $f_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ is non-Gaussian (Christakos 1992: 162–164). This is not surprising, since to a given univariate PDF, one may associate more than one bivariate PDF. Many other examples are found in the cited literature.

Some useful properties of the factorable S/TRF model may grab the readers' attention, and so may do its limitations. If $X_{\boldsymbol{p}}$ is such an S/TRF field and $\phi(\cdot)$ is a strictly monotonic function, the random field $Z_{\boldsymbol{p}} = \phi(X_{\boldsymbol{p}})$ is also factorable. This means that starting from the known classes of factorable fields $X_{\boldsymbol{p}}$, new classes $Z_{\boldsymbol{p}}$ can be constructed using different kinds of $\phi(\cdot)$. In the bivariate case ($k = 2$), the PDF is written as $f_{Z;\boldsymbol{p}_1,\boldsymbol{p}_2} = f_{Z;\boldsymbol{p}_1} f_{Z;\boldsymbol{p}_2} \sum_{j=0}^{\infty} \theta_j \varpi_j[\phi^{-1}(\zeta_{\boldsymbol{p}_1})] \varpi_j[\phi^{-1}(\zeta_{\boldsymbol{p}_2})]$. Another interesting property of the factorable model is that it satisfies the relationship

$$\int d\chi_{\boldsymbol{p}_1}(\chi_{\boldsymbol{p}_1} - \overline{X_{\boldsymbol{p}_1}}) f_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = c_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} \sigma_{X;\boldsymbol{p}_2}^{-2} (\chi_{\boldsymbol{p}_2} - \overline{X_{\boldsymbol{p}_2}}) f_{X;p_2}, \tag{5.25}$$

for all $\boldsymbol{p}_1, \boldsymbol{p}_2$. Remarkably, (5.25) is valid for S/TRF classes other than factorable. In the special case that $\overline{X_{\boldsymbol{p}_i}} = \overline{X} = \mu$ and $f_{X;\boldsymbol{p}_i} = f_X$ (for all $\boldsymbol{p}_i$), Eq. (5.25) reduces to a more tractable form, $\int d\chi_{\boldsymbol{p}_1}(\chi_{\boldsymbol{p}_1} - \mu) f_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = \rho_{X;\boldsymbol{h},\tau}(\chi_{\boldsymbol{p}_2} - \mu) f_X$, $\boldsymbol{h} = |\boldsymbol{s}_1 - \boldsymbol{s}_2|$ and $\tau = |t_1 - t_2|$. A direct consequence of (5.25) is $\overline{X_{\boldsymbol{p}_1} X_{\boldsymbol{p}_2}^m} = \rho_{X;\boldsymbol{h},\tau} \overline{X_{\boldsymbol{p}_2}^{m+1}} - \mu(\rho_{X;\boldsymbol{h},\tau} - 1)\overline{X_{\boldsymbol{p}_2}^m}$; i.e., a higher-order, two-point dependence is conveniently expressed in terms of one-point functions. Other attractive properties emerging from formulation (5.25) could be considered by the interested readers. In fact, those among the readers with an eye for unconventional results may also wish to develop the multivariate (higher than two) version of Eq. (5.25). Yet, another interesting property of the factoras is that they can generate estimators of nonlinear state-nonlinear measurement systems that are superior to those of

[20] For example, the Gaussian, Gamma, or Poisson univariate PDF is associated with Hermite, Laguerre, or Charlier polynomials.

the Kalman filter (Christakos. 1989). For example, the Kalman filter estimates include only linear correlation, whereas the factora estimates include linear and nonlinear correlations; also, the Kalman filter is limited to the estimation of the lower-moments (mean and variance), whereas the factora estimator can provide lower- and higher-order moments.

5.6.1.4 Comparative Comments and Pontius Pilate's Evasion

Theorists are sometimes accused of having the tendency to make otherwise simple-minded ideas and concepts look impressive, by using a sufficient string of intimidating Greek symbols.[21] If this is indeed the case, no theorist can repeat Pontius Pilate's *αθώος του αίματος*[22] evasion, and claim innocence. But if this is not the case, one cannot really see the need to misrepresent complex ideas by making them look overly simple, in the name of a misplaced and misunderstood populism in science. In a nutshell, underlying both the copula and factora technologies is the basic idea of replacing an unknown entity (original multivariate PDF) with another unknown entity (factora or copula), which is supposedly easier to infer from the available data and manipulate analytically. Whether this is actually a valid claim of practical significance depends on a number of technical and substantive issues, some of which were touched upon in the previous lines.

In technical terms, a prime advantage of the copula technology is its analytical tractability, although this is mainly valid in low dimensions (2–4). While factoras involve infinite series that have to be truncated, many copulas are available in a closed-form. This comes at the cost of some restrictive assumptions made by copulas, such as low dimensionality, uniform marginals, and the applicability of the integral transform theorem. Attempts to involve transforms of uniform marginals are rather ad hoc and can add considerable complexity to the process. Potential advantages of factoras include the elimination of the above restrictive requirements, and the rich classes of PDFs derived by taking advantage of the ϕ-property and generalization formulas (like (5.25)). The functional form of $\theta_{X;\{\boldsymbol{p}_i\}}$ is explicitly given in terms of known polynomials, whereas the explicit form of $\varsigma_{X;\{\boldsymbol{p}_i\}}$ is generally unknown and needs to be derived every time.

5.6.2 Substantive Construction

Though the importance of theory in real-world IPS is undeniable, explicating the relationship between theory and in situ phenomena is a perennial epistemological issue. *A cette fin*, the substantive approach of constructing multivariate PDF adopts a definite science-based viewpoint. Readers are reminded that a prime source of substantive knowledge is provided by natural laws and scientific theories. Indeed,

[21] The situation may worsen if the theorist happens to be Greek.

[22] I am pure of this blood.

investigators often have at their disposal a well-established set of natural laws to work with (e.g., one can hardly imagine a physical law free atmospheric science). Most commonly these laws have the form of algebraic or differential equations (a list of natural laws is presented in Table 1.12), whereas the study of a natural law requires some auxiliary conditions in the form of boundary and/or initial conditions (BIC), see Section 5.5.3. The crux of the matter is that if the natural laws are known, this is core knowledge that should be used in the derivation of the PDF models, which is a definite advantage of substantive model construction (e.g., prior probability problems of the so-called objective and subjective Bayesian analyses could be avoided). One may distinguish between the direct involvement of natural laws in terms of the corresponding *stochastic equations* and their indirect involvement by means of the *knowledge synthesis* framework.

5.6.2.1 The Stochastic Equations Method

During the development of his kinetic theory of gases in the nineteenth century, Boltzmann rigorously demonstrated that reliable physical laws could be built on a stochastic foundation involving probability functions. In a similar vein, Sir Arthur Eddington remarked that, “It is impossible to trap modern physics into predicting anything with perfect determinism because it deals with probabilities from the outset” (Newman 1956). This is indeed the case of the stochastically formulated natural law (5.12) obeyed by attribute $X_{\boldsymbol{p}}$. In a symbolic form, the law that the corresponding $f_{X;\boldsymbol{p}}$ satisfies is Eq. (5.15). Its derivation from the stochastic law (5.12) is conceptually straightforward, but its practical implementation is often not an easy task.

When all coefficients are assumed fixed and only X_0 is random, Eqs. (5.12), (5.15) give

$$X_{\boldsymbol{p}} = M_X^{-1}(X_0) \rightarrow f_{X;\boldsymbol{p}} = M_f^{-1}(f_{X;0}). \tag{5.26}$$

A visual representation of Eq. (5.26) is attempted in Fig. 5.2, which indicates that stochastic laws have their rationale in symbolic language (in terms of mathematical attribute symbols) and visual language (probability shapes and function plots). Both languages are important in one’s effort to reproduce the laws of Nature into a coherent and comprehensive system of knowledge. Consider the Langevin-type equation $\gamma \frac{d}{dt} X_t = \sigma \xi_t$, where X_t denotes the velocity of a particle at time t, γ is a coefficient associated with the velocity-dependent frictional term, and ξ_t is a fluctuating force term with coupling coefficients σ. The corresponding physical probability (Fokker-Planck) equation is $\frac{\partial}{\partial t} f_{X_0}(X_t) = \nabla^2 \frac{\sigma^2}{2\gamma^2} f_{X_0}(X_t)$. For illustration, examples of two different ways to construct the PDFs from the physical laws are briefly examined next. The first example is the stochastic differential Eq. (5.13) of $X_{\boldsymbol{p}}$ with $X_0 \sim f_{X;\boldsymbol{s},0} = e^{\mu_0 + \mu_1 \chi_{s,0} + \mu_2 \chi_{s,0}^2}$, and known coefficients μ_i ($i = 0,1,2$). The analytical solution of (5.13) yields the attribute PDF (Gardiner 1990), $f_{X;\boldsymbol{p}} = e^{-bt + \mu_0 + \mu_1 \chi_{\boldsymbol{p}} e^{-bt} + \mu_2 \chi_{\boldsymbol{p}}^2 e^{-2bt}}$ as a function of $\boldsymbol{p}$. The second example uses a quantum system governed by the stochastic Schrödinger law (5.14). The associated

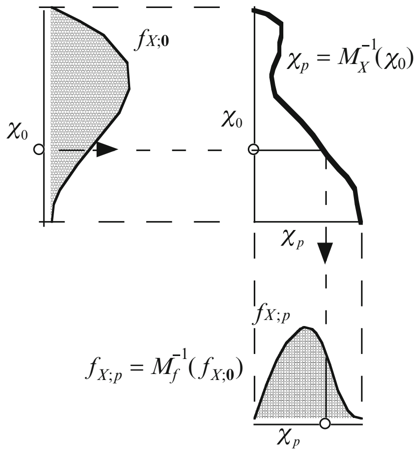

Fig. 5.2 A visual representation of Eqs. (11)

probability has the form $f_{\psi;\boldsymbol{p}} = |\psi_{\boldsymbol{p}}|^2$, i.e., the PDF is determined in a straightforward manner, as soon as the solution $\psi_{\boldsymbol{p}}$ of (5.14) is available.[23] Several other studies can be found in the literature which focus on the derivation of useful attribute probabilities from physical laws. In subsurface flow, e.g., one notices the pioneering work of Gedeon Dagan (1982, 1989) that includes both conditional and unconditional probabilities in heterogenous porous formations, and the research efforts of Shlomo Neuman and co-workers (Neuman, 2005: Neuman and Tartakovsky, 2009) who also considered stochastic flow in fractured rocks and anomalous transport.

5.6.2.2 The Knowledge Synthesis Method

Surely, knowledge comes to people through a non-uniform network of beliefs, presumptions, self-corrections, opinions, and experiences. In the face of this, it is difficult to exactly reconstruct the process of thought. Nevertheless, there are certain important major knowledge stages that can be outlined (at the very least) and offer inspiration for IPS purposes. Chapters 6–7 present a general knowledge synthesis framework for constructing multivariate PDFs in a manner that incorporates *G*-KB (natural laws, theoretical models, scientific theories, empirical relationships) and S-KB (site-specific knowledge like hard data, uncertain information, secondary sources) of the in situ situation.[24] In Section 6.5.1, the knowledge synthesis-based PDF is compactly expressed as

$$f_{X;\boldsymbol{p}} = A^{-1} \int d\boldsymbol{\chi}\, \xi_S\, e^{\boldsymbol{\mu}\cdot\boldsymbol{g}}. \tag{5.27}$$

[23] While Newton's laws deal with actual positions and velocities, the Schrödinger law essentially describes the evolution of probabilities.

[24] The core and the specificatory knowledge bases, *G*-KB and *S*-KB, respecitvely, were introduced in Section 1.2.3, and are discussed in detail in the Section 3.6.

where A is a normalization parameter, $\boldsymbol{g}$ is a vector with elements representing the G-KB (including the natural law), $\boldsymbol{\mu}$ is a space–time vector with elements that assign proper weights to the elements of $\boldsymbol{g}$ and ξ_S represents the S-KB available. When used in (5.27), the core knowledge widens horizons by abiding with site-specific data by a process of integrating S with G in a physically and logically consistent manner. Equation (5.27) accounts for local and nonlocal attribute dependencies across space–time. The above are noticeable advantages of the knowledge synthesis method of PDF building, which is why its description covers two of the following chapters.

5.6.3 Drunkard's Search

It is worth reviewing some technical and interpretive features of the methods used to construct a PDF. When the formal approach of Section 5.6.1 is favored, the PDF can have a variety of shapes, as long as certain conditions are fulfilled (satisfaction of the mathematical PDF admissibility requirements); and when selected from the list of models available in the literature, the PDF should not be merely a convenient choice but also a physically meaningful and internally consistent model whose parameters are obtained from the databases. When, on the other hand, the substantive methods of Section 5.6.2 are chosen, the PDF is derived directly from the in situ situation (physical laws, biological models, social constructs). Definite advantages of this method include that the derived PDFs have physical substance, and one may not need to check whether the technical conditions of Section 5.6.1 are satisfied. An obvious difficulty is that natural laws may not be available for all in situ situations. But in this case, many thinkers argue, it may be appropriate to admit that no sufficient in situ knowledge is available to pursue the task (of PDF construction) at the present time. Indeed, there is a considerable number of problems that the scientific method can solve and also a number of problems that cannot be currently solved on the basis of the existing data and current knowledge.

What the readers should take home from the discussion so far is that the search for the most adequate PDF model should be wide open and not merely a drunkard's search.[25] In some cases, the convenience of the formal approach may be a reasonable option, whereas in other applications a substantive approach will need to be used that accounts for physical and other kinds of knowledge sources. As already noted, a challenge faced by PDF modelers is how best to present detail-drenched in situ phenomena alongside theoretical constructions without twisting the former beyond recognition or viewing the latter as an interesting but unrealistic abstraction. On occassion, the real search begins with the recognition of clues. Like in detective novels or history books, the development of PDF rests on highlighting minuscule clues that may shed small beams of light on a hidden picture inferred by induction rather than deduced from general principles.

[25] The drunk looks for the lost keys only under a sidewalk lamp because this is where the best light is.

5.7 Spatiotemporal Dependence and Woody Allen's Prose

When a thing is funny, search it for a hidden truth. In a hilarious passage, characteristic of Woody Allen's prose, reference is made to "the bizarre experience of two brothers on opposite parts of the globe, one of whom took a bath while the other suddenly got clean" (Allen 1998: 16). Allen's special brand of humor portrays a case of spatiotemporal dependence, in which what happens in one space–time point strongly affects what happens in another point. In sciences there exist different ways to assess the space–time change (in the sense of stochastic causality or association) of a natural attribute, and each one of them has its *pros* and *cons*. One way may be a perfect fit for an end, but not for other ends.

5.7.1 Dependence in Terms of Stochastic Expectation

Useful S/TRF tools for assessing spatiotemporal change are the *dependence functions* of the attribute $X_{\boldsymbol{p}}$ defined in terms of stochastic expectation. In principle, these functions, say $D_{X_{\boldsymbol{p}}}$, can be calculated in terms of the PDF as follows:

$$D_{X_{\boldsymbol{p}}} = \overline{\Theta(\boldsymbol{\chi}_{\boldsymbol{p}})} = \int d\boldsymbol{\chi}_{\boldsymbol{p}}\, \Theta(\boldsymbol{\chi}_{\boldsymbol{p}}) f_{X;\boldsymbol{p}}, \tag{5.28}$$

where, as usual, the bar denotes stochastic expectation, Θ is a known function. A few examples of $D_{X_{\boldsymbol{p}}}$ functions are given in Table 5.6. Some of these examples should look familiar to the readers, whereas some others may not. The covariance function, e.g., is obtained from the general Eq. (5.28) by letting $\Theta(\chi_{\boldsymbol{p}_i}, \chi_{\boldsymbol{p}_j}) = (\chi_{\boldsymbol{p}_i} - \overline{m}_{\boldsymbol{p}_i})(\chi_{\boldsymbol{p}_j} - \overline{m}_{\boldsymbol{p}_j})$, in which case $c_{X;\boldsymbol{p}_i,\boldsymbol{p}_j} = \iint d\chi_{\boldsymbol{p}_i} d\chi_{\boldsymbol{p}_j} \Theta(\chi_{\boldsymbol{p}_i}, \chi_{\boldsymbol{p}_j}) f_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}$.[26] The reader will observe that not all dependence functions can be derived from Eq. (5.28). This is, in fact, the case of the sysketogram and contingogram functions in Table 5.6 (we will revisit these functions later in this chapter). In principle, one can assume an

Table 5.6 Examples of spatiotemporal dependence functions.

Name	*Form*	
Mean:	$\overline{m}_{\boldsymbol{p}} = \overline{X_{\boldsymbol{p}}}$	(5.29)
Covariance:	$c_{X;\boldsymbol{p}_i,\boldsymbol{p}_j} = \overline{(X_{\boldsymbol{p}_i} - \overline{m}_{\boldsymbol{p}_i})(X_{\boldsymbol{p}_j} - \overline{m}_{\boldsymbol{p}_j})}$	(5.30)
Variogram:	$\gamma_{X;\boldsymbol{p}_i,\boldsymbol{p}_j} = \frac{1}{2}[\overline{(X_{\boldsymbol{p}_i} - X_{\boldsymbol{p}_j})^2} - (\overline{m}_{\boldsymbol{p}_i} - \overline{m}_{\boldsymbol{p}_j})^2]$	(5.31)
Multiple-point:	$g_{X;\{\boldsymbol{p}_i\},\lambda} = \overline{\prod_{i=1}^{\lambda}(X_{\boldsymbol{p}_i} - \overline{m}_{\boldsymbol{p}_i})}$	(5.32)
Sysketogram:	$\beta_{X;\boldsymbol{p}_i,\boldsymbol{p}_j} = \overline{\log(f_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}/f_{X;\boldsymbol{p}_i} f_{X;\boldsymbol{p}_j})}$	(5.33)
Contingogram:	$\psi_{X;\boldsymbol{p}_i,\boldsymbol{p}_j} = \overline{f_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}/f_{X;\boldsymbol{p}_i} f_{X;\boldsymbol{p}_j}} - 1$	(5.34)

[26] It is easily seen that the attribute *variance*, $\sigma^2_{X;\boldsymbol{p}_i}$, is obtained from $c_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}$ if we let $\boldsymbol{p}_i = \boldsymbol{p}_j$.

infinite number of Θ functions, and then calculate D_{X_p} from (5.28). At this point, one may legitimately ask: Since each D_{X_p} is calculated *in terms of* $f_{X;\boldsymbol{p}}$, how can D_{X_p} be used *instead of* $f_{X;\boldsymbol{p}}$? This is a legitimate question. Its answer will concern us next.

5.7.1.1 Abstract and Intuitive Appraisals of Reality

Most experts agree that the usefulness of the D_{X_p}-sets consists in their anticipated ability to express important aspects of the space–time attribute distribution in a form that is more convenient to use than the multivariate PDFs, which are often difficult to obtain or may have an arbitrary and difficult to interpret general shape (Bogaert 1996; Douaik et al. 2005; Law et al. 2006; Choi et al. 2007; Coulliette et al. 2009). In theory, assuming that $f_{X;\boldsymbol{p}}$ is known exactly, any D_{X_p} can be derived from Eq. (5.28). But a careful consideration of the matter shows that some important issues emerge in the real-world. If the $f_{X;\boldsymbol{p}}$ shape is completely unknown, how can one select a D_{X_p}-set that enables an adequate characterization of the attribute distribution across space–time? Also, assuming that a D_{X_p}-set has been somehow selected in theory, how can it be computed reliably from the limited databases? Plainly speaking, there are no generally valid answers to these questions. The fact that $f_{X;\boldsymbol{p}}$ may have an arbitrary shape creates serious difficulties concerning D_{X_p} selection. In many problems, the PDF shape is indeed completely unknown (one does not even know if the PDF is symmetric, etc.), which makes it difficult or even impossible to decide what sort of dependence functions to select. A trivial exception, of course, is the Gaussian case: the D_{X_p}-set (attribute mean and covariance) allows a formally complete characterization of $f_{X;\boldsymbol{p}}$. In the vast majority of PDF cases, however, this is not possible. Even if one makes a guess concerning the general shape of $f_{X;\boldsymbol{p}}$, it may be not possible, on the basis of the available datasets, to calculate those parameters that will allow an exact determination of the PDF. In a way, it is like the general solution of a differential equation that is not of much use in practice, unless realistic auxiliary conditions are available that allow the derivation of the particular solution of the in situ phenomenon.

But the situation may be not always as gloomy as seems to be implied above. Many space–time modeling experts claim that in a large number of in situ cases the D_{X_p} set consisting of the first three functions in Table 5.6, i.e.,

$$D_{X_p} = \left\{ \overline{X_{\boldsymbol{p}}},\ c_{X;\boldsymbol{p}_i,\boldsymbol{p}_j},\ \gamma_{X;\boldsymbol{p}_i,\boldsymbol{p}_j} \right\}, \tag{5.35}$$

can provide a formally incomplete yet practically satisfactory description of the attribute's space–time distribution (Jones and Zhang 1997; Kyriakidis and Journel 1999; Augustinraj 2002; Ma 2003; Fernandez-Casal et al. 2003; Douaik et al. 2005; Stein 2005; Gneiting et al. 2007; Porcu et al. 2006, 2008; among others). This may be a reasonable claim, as long as practicality is not confused with mere convenience. Furthermore, the apparent success of the dependence set (5.35) in practice is one of those unexpected yet welcomed "miracles" that sometimes occur in a scientist's life. I will call it a "disconcerting" miracle for reasons that will become clear later. It is true that the situation is much better in the exact than the non-exact sciences. In the former case, an attribute obeys a physical law or a well-tested empirical model, so that its values are causally linked across space–time. Then it makes sense to determine D_{X_p} that expresses this link in a stochastic way that accounts for the co-existence of spatiotemporal structure and chance. However, this is not necessarily valid in non-exact sciences, where the concept of dependence (correlation) may be less meaningful or even deceiving. The co-association between financial securities, e.g., is not measurable using correlation functions, because past history can never prepare one for the day when everything goes south (Salmon 2009: 112). Some experts suggest deriving mainstream dependence functions (like the covariance and variogram) in terms of copulas (Bardossy 2006; Bardossy and Li 2008). There exist other studies that favor the use of the sysketogram ($\beta_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}$) or contingogram ($\psi_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}$) functions (Christakos 1991a, 1992). Are there any sound criteria for favoring a specific set of dependence functions over another, or is it simply a case of *fides quaerens intellectum*? The answer to this "faith seeking understanding" sort of question depends on the relation between the abstract and intuitive appraisals of reality in terms of dependence functions, the space–time structure of the underlying phenomenon, and the IPS objectives. As it will be shown in the following sections, each dependence function has its *pros* and *cons*, but some of them contain more grains of truth than others.

5.7.1.2 Concerning Mainstream Dependence Functions

Let us make a few observations concerning the most commonly used set of space – time dependence functions. The attribute mean function $\overline{X_{\boldsymbol{p}}}$ is defined at each point of the continuum, it can be calculated at a local and/or a global scale, and it gives an idea about dominant trends in the spatiotemporal variation of the attribute. The covariance $c_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}$ and the variogram $\gamma_{X;\,\boldsymbol{p}_i,\boldsymbol{p}_j}$ measure the degree of agreement of attribute values at pairs of points $\boldsymbol{p}_i$ and $\boldsymbol{p}_j$. In other words, the covariance and the variogram functions show how dependence between pairs of attribute values changes with space–distance and time-lag (in commonly encountered cases, e.g., the observed reduction of covariance values with spatial distance and time lag implies a reduced space–time attribute dependency). This dependence is an inherent feature of the attribute's composite variation across geographical space and during different time periods. There exist, of course, different forms of space–time dependency, which lead to distinct covariance and variogram shapes that satisfy the required mathematical *permissibility* criteria.[27] The $c_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}$ and $\gamma_{X;\,\boldsymbol{p}_i,\boldsymbol{p}_j}$ models may

[27] A list of space–time covariance and variogram models together with their permissibility conditions can be found in Christakos (1991a, c, 1992, 2005b, 2008a, b), Christakos and Hristopulos (1998), Gneiting (2002), Kolovos et al. (2004), Christakos et al. (2000, 2005), and Porcu et al. (2006, 2008).

Table 5.7 Methods for constructing space–time dependence models

Space transforms (ST)	Probability distribution (PD)
Laws of Nature (LN)	Generalized random measure (GM)
Spectral measure (SM)	Permissible combinations of valid models (PC)

be space–time *separable* (e.g., they are expressed as the product of purely spatial and purely temporal components), whereas other models are assumed to be *non-separable* (they cannot be expressed as the above product).

Alexander Kolovos and co-workers have described a variety of mathematical and physical methods that can be used to construct valid space–time dependence models for the D_{X_p}-set of Eq. (5.35), separable and non-separable (Table 5.7; details can be found in Kolovos et al. 2004 and references therein). Using the ST method, dependence models in higher dimensionality domains are obtained from functions that are permissible in a lower dimensionality domain. The LN method expresses natural laws in a stochastic form, and the associated dependence functions are derived accordingly (see also the following Section 5.7.2). Using the SM, PD, and GM methods, valid dependence models are obtained from different kinds of measures by means of appropriate operations. In the PC method various combinations of existing permissible models can generate rich families of new space–time dependence functions. It is a matter of choice what knowledge bases and methods of analysis one should use. Each choice has its own merits and domain of applicability. However, there are cases where rationality and rigor require that some bases and methods be preferred over others. Many experts are critical of data-driven regression modeling that uses a fixed list of covariance models, independent of the underlying physics, rather than deriving them on the basis of substantive knowledge. On the other hand, the Spartan random field modeling of Dionissios T. Hristopulos[28] and co-workers properly uses covariance models established by means of physically or intuitively motivated interactions, instead of a purely data-driven matrix (Hristopulos 2003; Elogne et al. 2008).

5.7.1.3 The Indiscrimination Property

Studying space–time dependence functions, rather than the complete PDFs, is often a legitimate way of confronting S/TRF theory with in situ observations, and then making informative space–time predictions. But one should be always reminded of the warning of Section 5.2.2 that the uncritical implementation of probabilistic analysis can be a slippery affair. A telling example is the so-called *indiscrimination* property of lower order dependence functions: the same covariance or variogram

[28] Beyond being a distinguished researcher, Hristopulos is an impressive performer capable of leaping across the dance floor in a series of faultless *grand jetés*. Talking about synthesizing personalities of large scope.

function can be assigned to random fields that exhibit very different space–time variation patterns (which may partially justify the characterization "disconcerting miracle" used earlier). Accordingly, the indiscrimination property raises legitimate questions regarding the validity of some theory–reality associations. The best response probably is to view the dependence function and the generated realizations in combination with other knowledge sources and analysis tools. Viewing a problem from the perspective of (intradisciplinary or interdisciplinary) knowledge synthesis is often a sound approach.

Let us consider a simple example. The two random fields X_s and Y_s are empirically related by $Y_s = v\,X_s$, where the field $v \sim U(0,\ 1)$ is independent of X_s and Y_s. Trivial calculations show that the two random fields have the same covariance, $c_{Y;\,s_i,\,s_j} \equiv c_{X;\,s_i,\,s_j}$. As one can see in Fig. 5.3, however, the two random fields can generate very different realizations representing the variation of the corresponding attribute, which means that the "black box" use of the covariance can provide a poor representation of the actual variation. In many cases, the situation can be improved significantly by conditioning the generated realizations with good quality datasets. In sum, the covariance and variogram functions should be used only when there is a deeper understanding and a valid working hypothesis about the natural system. Understanding guides one's sensory engagement with in situ evidence, and improves one's interpretation of the dependence functions calculated from this evidence.

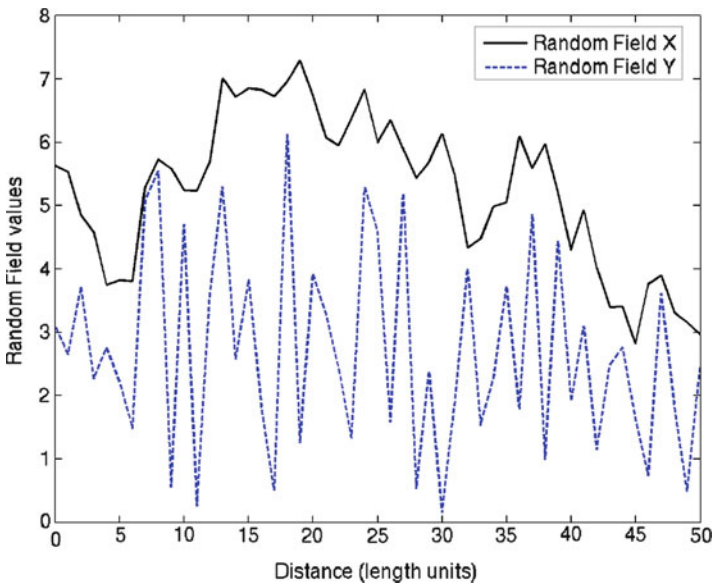

Fig. 5.3 Realizations of two random fields sharing the same covariance form

5.7.2 Dependence in Terms of Natural Laws

I hope the readers like ancient legends as much as I do. While considering dependence functions, the legend of the Irish king Fergus Mac Leda came to my mind. The king used to take long journeys in the land of Ireland, until he encountered a fierce river horse in Loch Rury. The encounter so terrified Fergus that his face became permanently distorted with fear. He kept on thinking about the incident, and since it was a matter of honor for the king to resolve the situation, he returned to Loch Rury several times to confront the monster. During the final struggle, Fergus managed to slay the monster before going down himself. But having finally resolved the matter, the king's face at last was restored and serene. It is not unusual that contemporary investigators find themselves in Fergus' position, hopefully with a few variations. During their long journeys in the land of scientific inquiry, the investigators too encounter difficult problems and serious obstacles that they cannot handle at the time, but they keep on thinking about them until they are able to finally resolve them. Let us apply this approach in the case of space–time dependence characterization, and revisit the issue of how to adequately develop the corresponding models.

Returning to the problem of space–time dependence representation, if an investigator seeks to construct a dependence model from incomplete datasets, one needs to have an understanding of what kind of space–time structure one is looking for. This understanding comes, *inter alia*, from natural laws of various kinds. This is the basic idea underlying the LN method for constructing dependence models (Table 5.7). The method has two versions. In the first version, after the solution $X_{\boldsymbol{p}}$ of the stochastic attribute Eq. (5.12) has been obtained, the dependence functions can be derived using Eqs. (5.29)–(5.32) in Table 5.6. In the second version of the LN method, the stochastic causality of (5.12) gives rise to the deterministic causality that connects the space–time dependence of the relevant attributes by means of the general model

$$M_D(D_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}) = 0, \tag{5.36}$$

where $D_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}$ denotes the dependence function set of the attribute $X_{\boldsymbol{p}}$ across space–time, and M_D includes the known dependence sets of a_i and X_0. Equation (5.36) is very informative: it shows how the dependence functions propagate across space–time so that they are consistent with the attribute's natural law. It is doubtful that this kind of information can be extracted from the incomplete dataset alone. In this sense, (5.36) unites the various space–time patterns emerging from natural law in a single network. Its solution gives $D_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}$ between all pairs of points $\boldsymbol{p}_i$, $\boldsymbol{p}_j$. For illustration, consider the temporal variation of the pollutant burden on a human organ, X_t, that obeys the stochastic kinematics law (Christakos and Hristopulos 1998: 284),

$$\tfrac{d}{dt} X_t + \lambda_t X_t - U_t = 0, \tag{5.37}$$

given $X_0 = 0$ (IC), U_t is the random uptake rate, and λ_t is the random transfer rate out of the organ. This implies, e.g., that the pollutant was first introduced in another compartment at $t = 0$ and then transferred to the compartment (5.37). The covariance of the burden fluctuation is governed by

$$D_{t_i} D_{t_j} c_{X;\, t_i, t_j} = \alpha\, e^{-\varepsilon|t_j - t_i|}, \tag{5.38}$$

where $D_{t_i} = [\frac{d}{dt_i} + \overline{\lambda_{t_i}}]$, α is the known variance of the uptake rate fluctuation, and ε^{-1} is the correlation time of the biological field. Equation (5.38) shows how the burden covariance propagates in the time domain. If one assumes that $c_{X;\, 0,\, 0} = 0$ (IC), and $\overline{\lambda} = \overline{\lambda_t}$ is constant, Eq. (5.38) can be solved for the burden covariance

$$c_{X;\, t_i,\, t_j} = \frac{\alpha}{\overline{\lambda}^2 - \varepsilon^2}[e^{-\varepsilon|t_j - t_i|} - \frac{\varepsilon}{\overline{\lambda}} e^{-\overline{\lambda}|t_j - t_i|} + \frac{\overline{\lambda} + \varepsilon}{\overline{\lambda}} e^{-\overline{\lambda} t_i - \overline{\lambda} t_j} - e^{-\varepsilon t_i - \overline{\lambda} t_j} - e^{-\overline{\lambda} t_i - \varepsilon t_j}]. \tag{5.39}$$

Eq. (5.39) is a symmetric function with respect to t_i and t_j. The burden covariance depends on the absolute time lag $|t_j - t_i|$, as well as on the disposition of both t_i and t_j with respect to uptake initiation (the burden is nonstationary, even when the uptake rate covariance is stationary). As it happens, theoretical toxicokinetics is ahead of its experimental counterpart, which means that advances in public health knowledge have to wait until the necessary experimental techniques are developed that can measure certain parameters of toxicokinetics models like Eqs. (5.38)–(5.39). Last but not least, consider a neuron morphology in which the evolution of the nerve cell potential $X_{\boldsymbol{p}}$ obeys the stochastic equation

$$[\frac{\partial^2}{\partial s^2} - \frac{\partial}{\partial t} - 1]\, X_{\boldsymbol{p}} + a \frac{\partial^2}{\partial s \partial t} W_{\boldsymbol{p}} + b = 0,$$

where s varies within a nerve cylinder, $t \geqslant 0$, a and b are constants, $W_{\boldsymbol{p}}$ is a white-noise field with covariance $c_{W;\boldsymbol{p}_i, \boldsymbol{p}_j} = \delta_{s_i, s_j}\, \delta_{t_i, t_j}$, and the cell is initially at rest. Then, under certain conditions (cell potential is initially zero, an infinite nerve cylinder is assumed, and smoothness requirements are met; Tuckwell 1989:69), the potential mean and variance are found from the above equation to be, $\overline{X_{\boldsymbol{p}}} = b(1 - e^{-t})$ and $\sigma^2_{X,\boldsymbol{p}} = \frac{1}{4} a^2 [1 - erfc(\sqrt{2t})]$.

5.7.3 *The Predictability Power of a Model*

The predictability power of the model M_D of the previous section may be considered in terms of its predictability *ranges* across space and time ($\varepsilon_{\boldsymbol{s}}^M$ and ε_t^M, respectively). Let $c_X^{M,S}(\boldsymbol{h},\ \tau)$ denote the spatiotemporal covariance between the $X_{\boldsymbol{p}}$ values generated by M_D and those obtained from the attribute dataset S. The $(\varepsilon_{\boldsymbol{s}}^M,\ \varepsilon_t^M)$ set is defined such that

$$c_X^{M,S}(\varepsilon_{\boldsymbol{s}}^M,\ \varepsilon_t^M) = \eta\, c_X^0, \tag{5.40}$$

where $\boldsymbol{h} = \varepsilon_{\mathbf{s}}^{M}$, $\tau = \varepsilon_{t}^{M}$, c_{X}^{0} is the corresponding variance, and the value of η is selected by the investigator to represent the desired level of model predictability (usually, $0.5 \leqslant \eta < 1$). Equation (5.40) provides a stochastic measure of similarity between the attribute values generated by M_D and S. The longer the spatial (temporal) range is, the higher is the spatial (temporal) predictability of M_D with respect to $X_{\boldsymbol{p}}$. The predictability ranges of M_D can be also compared to those of the dataset S. For example, S may include measurements $Y_{\boldsymbol{p}}$ via the empirical relationship $Y_{\boldsymbol{p}} = X_{\boldsymbol{p}} + W_{\boldsymbol{p}}$ ($W_{\boldsymbol{p}}$ is the measurement error due to equipment imperfections, site conditions, etc.). Let $c_{Y}^{S}(\boldsymbol{h}, \tau)$ be the $Y_{\boldsymbol{p}}$ covariance calculated on the basis of the S data, and let $c_{Y}^{S}(\varepsilon_{\boldsymbol{s}}, \varepsilon_{t}) = \eta c_{Y}^{0}$ define the corresponding correlation range set $(\varepsilon_{\boldsymbol{s}}, \varepsilon_{t})$. In this case the $c_{X,Y}^{M,S}(\boldsymbol{h}, \tau)$ denotes the spatiotemporal covariance between the X_p values generated by the model M_D and the $Y_{\boldsymbol{p}}$ values obtained from the dataset S; and $\varepsilon_{\boldsymbol{s}}^{M}$, ε_{t}^{M} are the associated space and time ranges. If the model M_D provides an adequate representation of the attribute distribution one should expect that $\varepsilon_{\mathbf{s}}^{M} > \varepsilon_{s}$ and $\varepsilon_{t}^{M} > \varepsilon_{t}$.

The readers may notice that in the limit when $\varepsilon_{\boldsymbol{s}}^{M} = \varepsilon_{\boldsymbol{s}}$ and $\varepsilon_{t}^{M} = \varepsilon_{t}$, M_D is not an improvement over the dataset S, in the predictability sense above. This is a point to be carefully investigated when using statistical regression and time series models in real-world applications (Smith et al. 2000; Hwang and Chan 2002; Martin and Roberts 2008). Since these models express $X_{\boldsymbol{p}}$ as a function of S data, the derivation of $c_{X,Y}^{M,S}(\boldsymbol{h}, \tau)$ is essentially based on the same dataset as $c_{Y}^{S}(\boldsymbol{h}, \tau)$, and so does the calculation of the coefficients of the statistical models. Hence, under certain circumstances it is possible that $\varepsilon_{\boldsymbol{s}}^{M} \approx \varepsilon_{\boldsymbol{s}}$ and $\varepsilon_{t}^{M} \approx \varepsilon_{t}$, which is a result that may doubt the validity of the models.

5.7.4 Information Theoretic and Copula Dependence Functions

Given the fundamental doctrine of scientific inquiry that one should always search for alternatives, I suggest examining the possibility of space–time dependence functions that lie outside the framework of the mainstream dependence functions. We start with the sysketogram $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} \geq 0$, Eq. (5.33), which is also written as

$$\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = \overline{\log f_{X;\boldsymbol{p}_1}^{-1}} - \int d\chi_{\boldsymbol{p}_2} f_{X;\,\boldsymbol{p}_2} \overline{\log f_{X;\,\boldsymbol{p}_1|\boldsymbol{p}_2}^{-1}}; \tag{5.41}$$

i.e., it is a spatiotemporal dependence measure with information-theoretic properties. Eq. (5.41) may be viewed in the context of the Kullback-Leibler divergence $D(f_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}; f_{X;\boldsymbol{p}_1}, f_{X;\boldsymbol{p}_2})$, where the D form is logarithmic. The sysketogram has some noticeable properties: in the case of stochastic independence (Section 5.6.1.1), it is valid that $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = 0$. The sysketogram depends only on the PDF and not the

$X_{\boldsymbol{p}}$ values.[29] And it is not affected if $X_{\boldsymbol{p}}$ is replaced by some function $\phi(X_{\boldsymbol{p}})$, provided that ϕ is one-to-one.[30] The last property means that $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ is an absolute rather than a relative quantity, in the sense that the space–time correlation defined by $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ is completely independent of the scale of measurement of $X_{\boldsymbol{p}}$. This property is useful in physical applications in which the concepts of "scale of measurement" and "instruments window" play an important role. Similarly, when the attribute has random space–time coordinates (e.g., distribution of aerosol particles), $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ is independent of the coordinate system chosen. The absoluteness property brings to mind a basic result of modern physics, according to which only absolute quantities (independent of the space–time coordinate system) can be used as essential components of a valid physical law (in which case the term "covariant" is used).

Another possible measure of space–time dependence is the contingogram $\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$, which is based on Karl Pearson's original idea of a discrete contingency coefficient. In the continuous space–time domain, the counterpart of Pearson's contingency was defined in Eq. (5.34).[31] The contingogram can be also written as

$$\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = \int\int d\chi_{\boldsymbol{p}_1} d\chi_{\boldsymbol{p}_2} f^2_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} (f_{X;\boldsymbol{p}_1} f_{X;\boldsymbol{p}_2})^{-1} - 1, \tag{5.42}$$

which shows that in the case of stochastic independence, $\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = 0$. As was the case with $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$, the $\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ depends only on the PDF of $X_{\boldsymbol{p}}$, and is not affected if the $(X_{\boldsymbol{p}})$ is replaced by the one-to-one function $\phi(X_{\boldsymbol{p}})$. From a stochastic reasoning viewpoint, $X_{\boldsymbol{p}}$ characterization provided by $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ and $\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ is cognitively general. The reader may notice a certain similarity between their definitions in Eqs. (5.33)–(5.34). Both dependence functions offer measures of the degree of $X_{\boldsymbol{p}}$'s departure from stochastic independence. It is noteworthy that if $A = f_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}/f_{X;\boldsymbol{p}_1} f_{X;\boldsymbol{p}_2}$, then $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = \overline{\log A}$ and $\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = \overline{A} - 1$. And by using series expansions[32] (small A values), one finds $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} \approx \overline{A - 1} = \psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$. At the moment, little is known about the in situ performance of $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ and $\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$, which remains an open field of research.

There are more space–time dependence functions that do not readily fit the general formulation of Eq. (5.28). One of them is defined as follows. To an S/TRF $X_{\boldsymbol{p}}$ one can associate the indicator random field: $I_{X;\boldsymbol{p},\zeta} = 1$ if $X_{\boldsymbol{p}} < \zeta$ (ζ is a cutoff), and $I_{X;\boldsymbol{p},\zeta} = 0$ otherwise. The corresponding indicator variogram of geostatistics can be written as (Bardossy 2006)

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[29] This is easily seen in the discrete case, $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = \sum_i f_{1;i} \log f^{-1}_{1;i} - \sum_j f_{2;j} \log f^{-1}_{1|2}$, where only the probability values are needed and not the numerical values of the realizations.

[30] That is $(\chi_{\boldsymbol{p}_1}, \chi_{\boldsymbol{p}_2}) \to (\chi'_{\boldsymbol{p}_1} = \phi(\chi_{\boldsymbol{p}_1}), \chi'_{\boldsymbol{p}_2} = \phi(\chi_{\boldsymbol{p}_2}))$, in which case $f_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} d\chi_{\boldsymbol{p}_1} d\chi_{\boldsymbol{p}_2} = f'_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} d\chi'_{\boldsymbol{p}_1} d\chi'_{\boldsymbol{p}_2}$

[31] Actually, Pearson defined the discrete-valued contingency as $\varphi = \left[\sum_i \sum_j \frac{\eta^2(\chi_i,\chi_j)}{\eta(\chi_i)\eta(\chi_j)} - 1\right]^{0.5}$, where η denotes discrete probabilities. Here the idea is extended in a continuous space–time domain with $\psi = \varphi^2$.

[32] That is, $\log A = (A-1) - \frac{1}{2}(A-1)^2 + \frac{1}{3}(A-1)^3 - \ldots$

$$\gamma_{I_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}} = F_X^{-1}(\zeta) - C_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}(F_X^{-1}(\zeta), F_X^{-1}(\zeta)), \tag{5.43}$$

where

$$C_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = P[F_X(X_{\boldsymbol{p}_1}) \leqslant \upsilon_{\boldsymbol{p}_1},\ F_X(X_{\boldsymbol{p}_2}) \leqslant \upsilon_{\boldsymbol{p}_2}] = C_X[F_X(X_{\boldsymbol{p}_1}),\ F_X(X_{\boldsymbol{p}_2})] \tag{5.44}$$

is the space–time dependence copula. One may, also, express $\gamma_{I_{X;p_1,p_2}}$ in terms of the space–time copula density, $f_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = (f_{X;\boldsymbol{p}_1} f_{X;\boldsymbol{p}_2})\, \varsigma_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$. An interesting property of (5.43)–(5.44) is that they express space–time dependence not in terms of the bivariate probability, but as a function of the corresponding univariate probabilities. This convenience often comes at a cost, which should be taken into consideration (Section 5.6.1). Just as is the case with the direct determination of the $f_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ shape, Bardossy says, the determination of the C_X form remains a difficult problem with no general solution available. In the same setting, the copulas do not contain different or more information than indicator variograms, but they allow a joint handling and a different presentation with a more parsimonious parameterization. As it turns out, the $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ and $\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ functions can be also expressed in terms of copulas: i.e.,

$$\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = \int_0^1 \int_0^1 d\upsilon_{\boldsymbol{p}_1} d\upsilon_{\boldsymbol{p}_2}\, \varsigma_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} \log \varsigma_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = \overline{\log \varsigma_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}}; \tag{5.45}$$

and,

$$\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = \int_0^1 \int_0^1 d\upsilon_{\boldsymbol{p}_1} d\upsilon_{\boldsymbol{p}_2}\, \varsigma^2_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} - 1 = \overline{\varsigma_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}} - 1. \tag{5.46}$$

In view of Eq. (5.46), the readers may notice an analogy between $\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ and Kendall's rank correlation coefficient discussed by Francesco Serinaldi (2008)

$$\tau_k = 4 \int_0^1 \int_0^1 \boldsymbol{d}C_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} C_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} - 1 = 4\, \overline{C_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}} - 1, \tag{5.47}$$

where, as usual, $\boldsymbol{d}C_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = \varsigma_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} d\upsilon_{\boldsymbol{p}_1}\, d\upsilon_{\boldsymbol{p}_2}$. The readers may argue that in the copula-based expressions of $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ and $\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$, the arbitrarily complex $f_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ is essentially replaced by what can be an equally complex $\varsigma_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$. Nevertheless, according to Serinaldi the advantage of expressing $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ and $\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ in terms of copulas is that these expressions involve integrals on finite supports.

Some further comparison between the mainstream space–time dependence functions and the information-theoretic dependence functions above is instructive. The $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ and $\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ have properties that may favor their use in place of the covariance $c_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$: (*i*) $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = \psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = 0$ in the case of stochastic independence, whereas $c_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ may be 0 even when only space–time non-correlation holds; (*ii*) $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ and $\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ depend only on the PDF, whereas the $c_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ depends on both the PDF and $X_{\boldsymbol{p}}$ values. (*iii*) $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ and $\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ are not affected if $X_{\boldsymbol{p}}$ is replaced by a one-to-one function $\phi(X_{\boldsymbol{p}})$, which is not the case with $c_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$; and (*iv*) $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ and $\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ can be extended in a straightforward manner to the multipoint case using copulas. Property *i* implies that $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ and $\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ contain more information about space–time dependence than $c_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$; or that $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ and $\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ uncover dependence features that $c_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ does not. Using Schwartz's inequality, it is shown that $\rho^2_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} \leqslant \psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$. For the indicator field $I_{X;\boldsymbol{p},\zeta}$, it is valid that $\rho^2_{I_X;\boldsymbol{p}_1,\boldsymbol{p}_2,\zeta} = \psi_{I_X;\boldsymbol{p}_1,\boldsymbol{p}_2,\zeta}$. Concerning property *iv*, the sysketogram and contingogram can be expressed in terms of copulas in the multipoint case as well; i.e.,

$$\left.\begin{aligned} \beta_{X;\boldsymbol{p}_1,\ldots,\boldsymbol{p}_k} &= \overline{\log \varsigma_{X;\boldsymbol{p}_1,\ldots,\boldsymbol{p}_k}} \\ \psi_{X;\boldsymbol{p}_1,\ldots,\boldsymbol{p}_k} &= \overline{\varsigma_{X;\boldsymbol{p}_1,\ldots,\boldsymbol{p}_k}} - 1 \end{aligned}\right\}, \tag{5.48a - b}$$

respectively. Hence, as soon as the copula density $\varsigma_{X;\boldsymbol{p}_1,\ldots,\boldsymbol{p}_k} = \varsigma_{X;\boldsymbol{p}}$ is calculated using standard techniques, the multipoint sysketogram $\beta_{X;\boldsymbol{p}_1,\ldots,\boldsymbol{p}_k} = \beta_{X;\boldsymbol{p}}$ and contingogram $\psi_{X;\boldsymbol{p}_1,\ldots,\boldsymbol{p}_k} = \psi_{X;\boldsymbol{p}}$ can be calculated too.

5.7.5 Spatiotemporal Homostationarity

Spatially homogeneity and temporally stationarity in the wide sense, also termed *spatiotemporal homostationarity* (STHS), assumes that the space–time mean $\bar{m}$ of the attribute $X_{\boldsymbol{p}}$ is a constant throughout the space–time domain of $\boldsymbol{p}$, and the covariance and variogram are functions only of the space–time lag $\boldsymbol{p}_i - \boldsymbol{p}_j = (\boldsymbol{s}_i - \boldsymbol{s}_j,\ t_i - t_j) = (\boldsymbol{h}, \tau)$, see Table 5.8. As happens in similar modeling cases, to perceive an STHS attribute is not to see that actual attribute; it is to see (from the perspective of one who uses) STHS. For $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$ and $\psi_{X;\boldsymbol{p}_1,\boldsymbol{p}_2}$, the STHS may be defined in the strict sense involving the corresponding PDFs (the PDFs do not change by a transformation $\delta\boldsymbol{p}$ of the space–time coordinates); then, $\beta_{X;\boldsymbol{p}_1,\boldsymbol{p}_2} = 0$ ($|\boldsymbol{p}_1 - \boldsymbol{p}_2| \to \infty$). The vector distance $\boldsymbol{h} = (r, \theta)$ consists of its magnitude $|\boldsymbol{h}| = r$ and its direction (angle θ). A special case of homogeneity is spatial *isotropy*: the covariance depends only on r (not on θ). Also, another way of looking at the set Θ (Fig. 4.1a) is like a set of iso-covariance contours.

The need to use simplified assumptions (such as STHS, low-order dependence functions, etc.) in real-world studies provides investigators with a perspective from which to interpret potentially significant gaps between theory and practice. Moving between theory and practice can help investigators appreciate the impact what they do has in what they think. Lastly, commonly used terms like "homogeneity,"

Table 5.8 Dependence functions for STHS fields (wide-sense)

Mean:	$\overline{X_{\boldsymbol{p}}} = \bar{m}$	(5.49)
Covariance:	$c_{X;\boldsymbol{p}_i,\boldsymbol{p}_j} = c_{X;\boldsymbol{p}_i-\boldsymbol{p}_j}$	(5.50)
Variogram:	$\gamma_{X;\boldsymbol{p}_i,\boldsymbol{p}_j} = \gamma_{X;\boldsymbol{p}_i-\boldsymbol{p}_j}$	(5.51)

"stationarity," "stochastic," and "isotropy" are sometimes misunderstood, and misused. Non-stationarity, e.g., has been associated with a white-noise process, and stochasticity has been confused with spatial stationarity (Cliff and Ord 1981). As a consequence, it is suggested to use the term homogeneity instead of stationarity in the spatial case, and keep stationarity for the temporal component of the variation (Yaglom 1961).

5.8 A Generalized View of S/TRF

In real life, one is often faced with the so-called "extension" problem. Scientists, for example, constantly seek to develop mental constructs that creatively extend an existing theory in order to include new and previously unobserved phenomena, solve previously unsolvable problems, and generate new and unexpected results.

5.8.1 Random Fields Based on Generalized Functions or Distributions

In the early 1950s, the need emerged to extend the homogeneous spatial random field (SRF) theory to include fields with spatially nonhomogeneous features.[33] Responding to this need, the theory of generalized SRF was developed (Yaglom and Pinsker 1953; Gelfand 1955; Yaglom 1957) based on the mathematics of generalized functions (or distributions),[34] in the sense of Laurent Schwartz and Kiyoshi Ito (Schwartz 1950; 1951; Itô 1954). In the 1970s, parts of the generalized theory were repackaged and extended in a geostatistics context, in which case the term "intrinsic SRF" was introduced (Matheron 1973). Another extension of the generalized theory was suggested in the composite space–time domain of Section 4.2. The extension was able to study physical attributes with heterogeneous space–time variability features, and led to the development of the *heterogeneous* S/TRF theory (Section 5.3.2), which is considerably richer than the STHS class, i.e. the S/TRF theory can be linked to a larger number of in situ phenomena than the STHS one. Random fields with spatial and temporal heterogeneity orders ν and μ, respectively, and the associated support functions, satisfy physical law-based conditions of change in the composite space–time domain. In the same setting, several classes of fractal and wavelet fields were derived as special cases of the heterogeneous S/TRF theory for suitable choices of the heterogeneity orders and support functions.

[33] Again, it is preferable that "nonstationary" be associated with time series rather than spatial functions, the latter being linked to the term "nonhomogeneous."

[34] Also known as SRF with homogeneous spatial increments of order ν.

5.8.2 An Operational Treatment of Space–Time Heterogeneous Attributes

Heterogeneous S/TRF theory (Christakos 1990a, 1991a, c, 1992, 2008a, b) is subject to the rules of engagement between the mind (mental construct) and its object of study (reality). In the following, for generality's sake, I assume that the space–time distribution of the attribute $X_{\boldsymbol{p}} = X_{\boldsymbol{s},t}$ of interest is heterogeneous.[35] Also, for reasons that will become clear soon, the focus is on S/TRFs that satisfy the formulation

$$Q_{\nu/\mu}[X_{\boldsymbol{p}}] = Y_{\boldsymbol{p}}, \tag{5.52}$$

where $Q_{\nu/\mu}$ is a space–time operator, the parameters ν and μ characterize the degrees of $X_{\boldsymbol{p}}$ heterogeneity in space and time, respectively; and the field $Y_{\boldsymbol{p}}$ exhibits some specified characteristics that serve an in situ objective (e.g., it is STHS). Throughout the book, an attempt has been made to demonstrate and to advocate the fruitfulness of understanding quantitative concepts in terms of literary metaphors. Resorting to such a metaphor, the paradoxical interchange between heterogeneous and homogeneous features is perceptible in Goethe's novel *Wilhelm Meister* expressed as the unusual co-existence of liberalism and absolutism, or in Beethoven's musical composition in which dynamic expositions and regular recapitulations form a binding entity. In the continuous case, the heterogeneity parameters (ν,μ) may imply spatial derivatives of order $\nu + 1$ and time derivatives of order $\mu + 1$ operating at the point $\boldsymbol{p} = (\boldsymbol{s}, t)$. This is a convention, according to which a STHS field has $\nu = \mu = -1$. If the PDF of $X_{\boldsymbol{p}}$ is known, it is possible to readily construct the $Q_{\nu/\mu}$ operator. In fact, if the operator expresses the dynamical laws that govern the natural attribute, the $X_{\boldsymbol{p}}$ is fully determined. Also, it is possible that the $Q_{\nu/\mu}$ operator of Eq. (5.52) enhances one's knowledge about the original attribute represented by the S/TRF $X_{\boldsymbol{p}}$. Assume that via $Q_{\nu/\mu}$ the $X_{\boldsymbol{p}}$ leads to $Y_{\boldsymbol{p}}$; then, the inverse operation $Q^{-1}_{\nu/\mu}$ may yield a new S/TRF representation of $X_{\boldsymbol{p}}$ that contains more knowledge than the original one.

There exist a large number of $Q_{\nu/\mu}$ choices in association with $X_{\boldsymbol{p}}$ (see examples in Table 5.9; Christakos 1992; Christakos and Hristopulos 1998). It is instructive to consider two main groups of operators, depending on the motivation behind their construction: Group *a* includes operators linked to substantive knowledge (natural laws, scientific theories, and empirical models). Equation (5.52) takes advantage of the fact that scientists often have at their disposal a set of sound natural laws to work with. In this sense, the heterogeneous S/TRF is a scientific method rather than a purely data-driven scheme, such as the statistical regression, time series, and hierarchical techniques. These techniques are satisfied with the mere description of data across space–time, whereas the S/TRF method has an explanatory character as a result of its connection with the laws describing the mechanisms underlying the

[35] Heterogeneity may be interpreted, e.g., in terms of complex spatial patterns combined with varying temporal trends (at local or global scales).

Table 5.9 Examples of $Q_{v/\mu}$ operators

$\frac{\partial^{v+\mu+2}}{\partial s_1^{v_1}\,\partial s_2^{v_2}\ldots\partial s_n^{v_n}\,\partial t^{\mu+1}}[\cdot],\ \sum_{i=1}^{n} v_i = v+1$
$\sum_{i=1}^{n}\frac{\partial^{v+\mu+2}}{\partial s_i^{v+1}\,\partial t^{\mu+1}}[\cdot]$
$\left(\frac{\partial^{\mu+1}}{\partial t^{\mu+1}}+\sum_{i=1}^{n}\frac{\partial^{v+1}}{\partial s_i^{v+1}}\right)[\cdot]$

data. Knowledge produced from these natural laws is used in the definition (5.52) of the S/TRF and the derivation of the corresponding dependence models. This leads to an exact specification of attribute dependence models about which limited or no information exists in terms of other attribute models about which sufficient information is available (e.g., the hydraulic head covariance is determined from the conductivity covariance using the continuity equation and Darcy's law).

Group b includes operators chosen so that they satisfy problem related requirements (e.g., they annihilate trend functions with space–time coordinates). Hence, S/TRFs defined by (5.52) are capable of handling complicated space–time patterns based on the intuitive idea that the variability of an attribute can be characterized by means of its degrees of departure from STHS. In Group b, more than one $X_{\boldsymbol{p}}$ are generated from $Y_{\boldsymbol{p}}$ by using different $Q_{v/\mu}$, which shows the generality of formulation (5.52). The notation S/TRF-v/μ is used to show that $Q_{v/\mu}$ eliminates composite space–time trends expressed in terms of polynomial functions $\vartheta_{v/\mu,\boldsymbol{p}}$ (of degrees v in space, μ in time). When an attribute $X_{\boldsymbol{p}}$ has certain features, f_i ($i = 1,\ldots,q$), and one or more of them are removed, it is physically possible that several of the remaining f_i cease to exist too. Which raises the question whether it is possible that by removing the heterogeneous features of $X_{\boldsymbol{p}}$, one also (unintentionally and unknowingly) removes some other features. The answer to this question is twofold: when $Q_{v/\mu}$ is based on a natural law, it is very likely that $Q_{v/\mu}$ will account for all essential features of the phenomenon; and the removal of the heterogeneity features, if it happens, is not permanent, since one returns to the original $X_{\boldsymbol{p}}$, after the necessary $Y_{\boldsymbol{p}}$-based analysis has been performed.

In the above setting, Eq. (5.52) underscores the conceptual and methodological significance of theory in scientific inquiry. Depending on the shape of $Q_{v/\mu}$, Eq. (5.52) can be formulated and solved in the continuous- or discrete-valued domain. A solution of (5.52) in the case, e.g., of the third operator in Table 5.9 is (Christakos and Hristopulos 1998),[36]

$$X_{\boldsymbol{p}} = \int d\boldsymbol{p}'\,\psi_{\boldsymbol{p}'}\,G_{0,\boldsymbol{p},\boldsymbol{p}'}^{(v+1/\mu+1)} + \overline{Y_{\boldsymbol{p}'}}\,\vartheta_{v/\mu,\boldsymbol{p}}. \tag{5.53}$$

[36] $\vartheta_{v/\mu,\boldsymbol{p}} = \frac{1}{(v+1)!}\sum_{i=1}^{n}\theta_i^2 \boldsymbol{s}_i^{v+1} + \frac{1}{(\mu+1)!}t^{\mu+1}$, $\sum_{i=1}^{n}\theta_i^2 = 1$, and the Green's function satisfies $Q_{v/\mu}[G_{0,\boldsymbol{p},\boldsymbol{p}'}^{(v+1/\mu+1)}] = \delta_{\boldsymbol{s}-\boldsymbol{s}'}\delta_{t-t'}$, where $\delta_{\boldsymbol{s}-\boldsymbol{s}'}$ and $\delta_{t-t'}$ are delta functions in space and time, respectively.

When the natural laws are not fully known, guidance regarding the form of $Q_{\nu/\mu}$ is offered by empirical relations expressed in terms, either of algebraic equations or algorithmic rules aiming to emulate physical reality. Last but not least, even if knowledge of the specific laws is not available, dependence models derived from generally applicable physical laws can be used as potential candidates for describing particular datasets, in which case the law parameters are estimated from these data. Some readers would notice that considering the mainstream paradigm that claims to reduce to simple formulas any kind of uncertainty by forcing people to think in terms of independent trials, to make bets, and to throw dices, the stochastic modeling issues discussed in this and other chapters may look as foreign to them as a Jackson Pollock expressionist creation would look to a painter of melodramatic scenes like Delaroche. Nevertheless, the complex real-world problems emerging with increasing frequency nowadays should convince one that these modeling issues do make sense and are very important indeed.

5.8.3 Spatiotemporal Dependence and Heterogeneity Parameters

The covariance $c_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}$ linked with S/TRF (5.52) is generally a heterogeneous space–time dependence function. Given the $Q_{\nu/\mu}$ shape, a variety of $c_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}$ models can be obtained, separable and non-separable. For illustration, the following covariance class is derived from a partial differential equation law (Christakos and Hristopulos 1998):[37]

$$c_{X;\boldsymbol{p}_i,\boldsymbol{p}_j} = \int_T d\tau' \int_V d\boldsymbol{h}'\, G_{1,\tau-\tau'}\, G_{2,\boldsymbol{h}-\boldsymbol{h}'}\, c_{Y;\boldsymbol{h}',\tau'} + \vartheta_{2\nu+1,\boldsymbol{h}} \vartheta_{2\mu+1,\tau} + \vartheta_{\nu/\mu,\boldsymbol{p}_i} \vartheta_{\nu/\mu,\boldsymbol{p}_j}. \tag{5.54}$$

Since the covariance (5.54) can be linked to substantive knowledge, the $c_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}$ expresses a degree of stochastic space–time causation that is significantly more than the mere statistical association measured by the purely data-driven covariance or variogram. Although this is an idea logically derivable from theoretical considerations and the existing evidence, the weakness of imagination may require a wealth of carefully acquired data to make the idea psychologically possible and its potential IPS impact well-understood. The matter could be an interesting avenue of future research.

[37] $G_{1,\tau-\tau'} = \frac{(-1)^{\mu}}{(2\mu+1)!}(\tau-\tau')^{2\mu+1}\theta_{\tau-\tau'}$ $(T = (-\infty,\tau])$, $G_{1,h-h'} = \frac{(-1)^{\nu}}{(2\nu+1)!}(h-h')^{2\nu+1}\theta_{h-h'}$ $(V = R^1)$, $G_{2,\boldsymbol{h}-\boldsymbol{h}'} = \frac{1}{2^{2\nu+1}\,\pi\,(\nu!)^2}|\boldsymbol{h}-\boldsymbol{h}'|^{2\nu}\log|\boldsymbol{h}-\boldsymbol{h}'|$ $(V = R^2)$, $G_{3,\boldsymbol{h}-\boldsymbol{h}'} = \frac{(-1)^{\nu+1}\,\Gamma(\frac{1}{2}-\nu)}{2^{2\nu+2}\,\pi^{3/2}\,\nu!}|\boldsymbol{h}-\boldsymbol{h}'|^{2\nu-1}$ $(V = R^3)$; $G_{2,\boldsymbol{h}-\boldsymbol{h}'} = G_{2,\boldsymbol{h}'-\boldsymbol{h}}$ $(V = R^2,\ R^3)$; θ is the unit step function.

5.8.3.1 Generalized Space–Time Dependence Models

Equation (5.54) can be written in the rather more concise form, $c_{X;\boldsymbol{p}_i,\boldsymbol{p}_j} = \kappa_{X;\boldsymbol{p}_i-\boldsymbol{p}_j} + \vartheta_{\nu/\mu,\boldsymbol{p}_i}\vartheta_{\nu/\mu,\boldsymbol{p}_j}$, where $\kappa_{X;\boldsymbol{p}_i-\boldsymbol{p}_j} = \kappa_{X;\boldsymbol{h},\tau}$ depends only on the space–time distance $\boldsymbol{p}_i - \boldsymbol{p}_j$.[38] An attractive feature of the decomposition is that in certain types of spatiotemporal analysis (e.g., linear prediction), only the $\kappa_{X;\boldsymbol{h},\tau}$ part is required. This decomposition has at least one important consequence: $\kappa_{X;\boldsymbol{h},\tau}$ can be constructed first, and then $c_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}$ is obtained by adding suitable space–time ϑ-functions. In relation to the last observation, it is valid that (Christakos and Hristopulos 1998: 148)

$$U_{Q_{\nu/\mu}}\kappa_{X;\boldsymbol{h},\tau} = c_{Y;\boldsymbol{h},\tau}, \tag{5.55}$$

where $U_{Q_{\nu/\mu}}$ is a space–time differential operator defined as the product of $Q_{\nu/\mu}$ and its complex conjugate operator.[39]

In the case of STHS, a set of computational formulas provide an efficient means for calculating experimental values of low-order dependence functions – such as the covariance $c_{Y;\boldsymbol{h},\tau}$ in Eq. (5.55) – from the available database. A valid model is subsequently fitted to the experimental values using a model fitting technique. If the data are *clustered* in space, efficient algorithms exist for the practical estimation of the sample covariance (Kovitz and Christakos 2004a): a coefficient of variation of the dimensionless spatial density of the point pattern of sample locations is introduced as a metric of the degree of clusteredness of the database, and a modified covariance estimator form is used that incorporates declustering weights and proposes a scheme for estimating the declustering weights based on zones of proximity. Given the covariance $c_{Y;\boldsymbol{h},\tau}$, Eq. (5.55) provides the means for constructing the corresponding models $\kappa_{X;h,\tau}$ and $c_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}$. For example, Equation (5.56) of Table 5.10 is linked to the simple case $c_{Y;\boldsymbol{h},\tau} = \delta_{\boldsymbol{h}}\,\delta_\tau$, whereas Eq. (5.57) is linked to $c_{Y;h,\tau} = ae^{-(bh+c\tau)}$ ($n = 1$). Space transforms (Table 5.7) offer a means to produce valid covariances in $R^2 \times T$ and $R^3 \times T$ starting from the known models in $R^1 \times T$ (Kolovos et al. 2004). It seems logical that the class of $\kappa_{X;\boldsymbol{p}_i-\boldsymbol{p}_j}$ models is richer than that of $c_{Y;\boldsymbol{h},\tau}$, and the class of $c_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}$ is richer than both.

5.8.3.2 On Fractal Space–Time Models

Data occasione, since fractal random fields (Feder 1988) constitute a special case of the richer class of S/TRF (5.52), several fractal covariances can be derived as

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[38] A terminology issue emerges here. Due to mathematical associations of Eq. (5.52) with the theory of generalized functions (distributions), and in order to distinguish it from the STHS covariance $c_{Y;\boldsymbol{h},\tau}$, it seems natural to call $c_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}$ a generalized spatiotemporal covariance, keeping in mind that the term "generalized covariance" has been used in physics (Joseph 1965) and geostatistics (Matheron 1973).

[39] For example, $U_{Q_{\nu/\mu}} = (-1)^{\nu+\mu}\,(\partial^{2\mu+2}/\partial\tau^{2\mu+2})\,(\nabla^2_{\boldsymbol{h}})^{\nu+1}$; Christakos and Hristopulos (1998: 160).

Table 5.10 Examples of $\kappa_{X;\boldsymbol{h},\tau}, r = |\boldsymbol{h}|$, models[40]

$c_0\delta_r\delta_\tau + \delta_r \sum_{\varsigma=0}^{\mu} (-1)^{\varsigma+1} a_\varsigma \tau^{2\varsigma+1} + \delta_\tau \sum_{\rho=0}^{\nu} (-1)^{\rho+1} b_\rho r^{2\rho+1} + \sum_{\rho=0}^{\nu} \sum_{\varsigma=0}^{\mu} (-1)^{\rho+\varsigma} a_{\rho\varsigma} r^{2\rho+1} \tau^{2\varsigma+1}, \quad n = 1, 2, 3,$	(5.56)
$(-1)^{\nu+\mu}[(2\nu+1)!(2\mu+1)!]^{-1} a\, b^{-2\nu-2} c^{-2\mu-2} e^{-br-c\tau} \gamma(2\nu+2, -br)\, \gamma(2\mu+2, -c\tau), \quad n = 1$	(5.57)

Table 5.11 Examples of fractal $\kappa_{X;\boldsymbol{h},\tau}, r = |\boldsymbol{h}|$, models[41]

$\kappa_{X;r,\tau} \propto r^\alpha \left(\tau/r^\beta\right)^z$	(5.58)
$\kappa_{X;r,\tau} = \sigma_X^2 \hat{f}_z(\tau/r^\beta; u_c) \hat{f}_\alpha(r; w_c)$	(5.59)

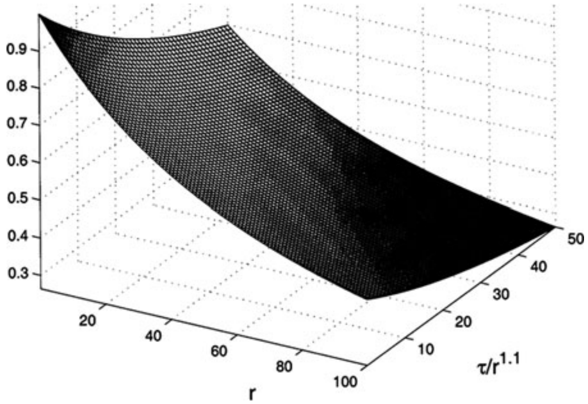

Fig. 5.4 Plot of the fractal covariance model for $\sigma_X^2 = 1$, $z = \alpha = -0.5$, $\beta = 1.1$, $u_c = w_c = 25$

special cases of $\kappa_{X;\boldsymbol{h},\tau}$. Examples are given in Table 5.11; the fractal model (5.59) is plotted in Fig. 5.4. The reader may notice that the function $\hat{f}_z$ has an unusual dependence on the space and time lags through τ/r^β. For large τ, the τ/r^β is close to 0 if r is sufficiently large and $\hat{f}_z$ is close to 1. With regard to $\hat{f}_z$, the equation for equidistant space–time contours is $\tau/r^\beta = c$. This dependence is physically different than that implied by, say, a Gaussian covariance model, in which case equidistant lags satisfy $r^2/\xi_r^2 + \tau^2/\xi_\tau^2 = c$. The difference is shown in Fig. 5.5 that plots the equidistant contours for $\hat{f}_z$ and $r^2/\xi_r^2 + \tau^2/\xi_\tau^2$ as a function of space and time lags. A class of fractal S/TRFs satisfies the mathematical relationship $X_{c^\eta \boldsymbol{s}, c^\xi t} = c^H X_{\boldsymbol{s},t}$ (in the self-similarity sense), where $X_{\boldsymbol{p}} = X_{\boldsymbol{s},t}$, $\boldsymbol{p} = (\boldsymbol{s}, t) \in R^n \times T$ $(n = 1,2,3)$, and $c > 0$, η, ζ, and H are the usual scaling coefficients. This class of fractal spatiotemporal random fields is denoted as *FS/TRF-H*. Under certain conditions, the corresponding expectation is written as $\overline{X^2_{c^\eta \boldsymbol{s}, c^\xi t}} = c^{2H} \overline{X^2_{\boldsymbol{s},t}}$. Consider the S/TRF (5.52), where $Q_{\nu/\mu}$ is the first operator in Table 5.9 and $Y_{\boldsymbol{p}}$ is a zero-mean STHS

[40] The coefficients $c_0, a_\zeta, b_\rho, a_{\rho\zeta}, a, b, c$ must satisfy certain permissibility criteria; δ_r and δ_τ are delta functions in space and time, respectively; and γ is an incomplete gamma function.

[41] The $r_0 << r << r_m$, $\tau_0 << \tau << \tau_m$ define space-time fractal ranges; $-1 < z < 0$, $-0.5\,(n+1) < \alpha - \beta z < 0$ are permissibility conditions; σ_X^2 is variance; u_c, w_c are cutoffs.

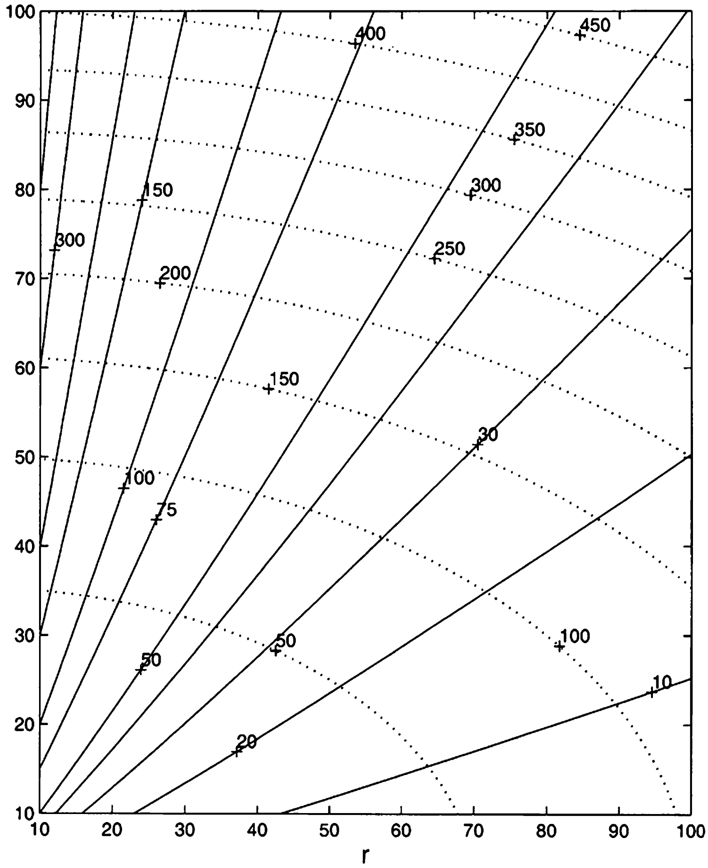

Fig. 5.5 Equidistant contours for fractal space–time dependence (*solid contours*) and for Gaussian dependence (*dotted contours*). Contour labels represent $c_0\tau/r^\beta$ values (*solid lines*) and $r^2/\xi_r^2+\tau^2/\xi_\tau^2$ values (*dots*) using $c_0 = 62.95$, $\xi_r = 10$ and $\xi_\tau = 5$

white-noise field with covariance $c_{Y;\boldsymbol{h},\tau} = 2D\delta_{\boldsymbol{h}}\,\delta_\tau$, where D is a suitable coefficient. Then, the FS/TRF-H is a member of the class of S/TRF-ν/μ subject to the condition $H = n(\nu + \frac{1}{2})\eta + (\mu + \frac{1}{2})\xi$.

5.8.3.3 Physical Interpretation of the Heterogeneity Parameters

In addition to making mathematical considerations, one should be prepared to shift the heterogeneous S/TRF theory one layer deeper. What, when, and how a scientist can investigate in situ situations is a function of the scientist's theoretical commitments and originality. In the case of the S/TRF theory, the heterogeneity parameters ν and μ of the $Q_{\nu/\mu}$ operator provide a quantitative assessment of the rate of change of attribute patterns across space–time, and also offer information about

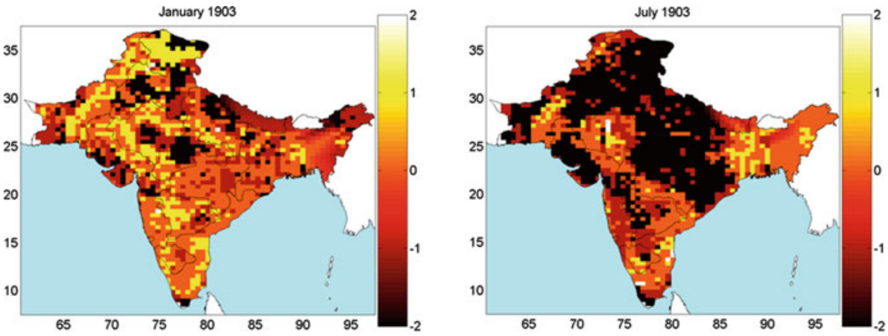

Fig. 5.6 Space–time maps of the $\nu - \mu$ differences associated with the Indian bubonic plague mortality distributions during different times (Yu and Christakos 2006)

the stochastic model representing the in situ system. These parameters, which are functions of space–time coordinates, determine, e.g., how "far" in space and how "deep" in time the operator searches for information about the attribute. Additional insight may be obtained by taking into consideration that the heterogeneity parameters ν and μ are directly related to the fractal coefficient H.

Plots of the $\nu - \mu$ values associated with mortality distributions in the case of the bubonic plague in India (late nineteenth–early twentieth century) are shown in Fig. 5.6. Note that the space–time covariance model (5.56) in Table 5.10 (with $n = 2$) was used in the Indian bubonic plague study. This study shows that the S/TRF (5.52) offers a general theoretical model of the population mortality distribution that reflects the way stochastic causal influence is propagated across space–time, and gives valuable information about the attribute dynamics at the scale of interest. Generally, for natural systems that evolve within domains containing complicated boundaries and trends, the degrees of S/TRF heterogeneity should vary geographically and dynamically.

5.9 Constructive Symbiosis and Its Problems

Comments such as the following sometimes appear in the literature: "A criticism of the utility of geostatistics in agriculture is that the mathematical framework in which it is usually presented is beyond many potential users" (Nelson et al., 1999: 311). Otherwise said, a theory that can offer an improved representation of Nature but requires some extra effort on the part of its practitioners, is doomed to failure (and together with it any attempt to "lift Isis' veil" – see Section 5.1). This is rather disappointing. Expert practitioners should appreciate the fact that theorists spend countless hours trying to create improved representations of reality, excogitating the vast physical world, and studying the significance of human existence within it. They struggle with new thoughts and imaginative mathematical constructs so that originality is not sacrificed to the Moloch of everyday pseudo-practicality. They continuously search for shreds of evidence and meaning hidden in every aspect of the world, because they believe that an unexamined world is a world not fully appreciated, a world not explored, investigated, and discovered. In a harmonic *symbiosis* with theorists, expert practitioners should view the in situ implementation of the fruits of the theorists' labor as a basic component of scientific inquiry, rather than a chore involving "bottom line" recipes and "black-box" software (so that their users can have a carefree life, frolicking in their field of expertise without bothering to address meaning and purpose).

Along the lines of constructive symbiosis, many in situ applications of the STRF theory can be found in the relevant literature, including environmental exposure, health effects, epidemiology, earth and atmospheric sciences, forestry, ecology, geography, and history.[42] A prime concern of these applications is not only to make possible the investigators' access to increased amounts of data, but most importantly, to present these data in a way that is consistent with the theory and improve the investigators' comprehension of the in situ phenomenon. This is made possible because, although their precise methods of inquiry differ from one discipline to the next, the investigators basically understand one another and share overlapping intellectual goals.

Naturally, the effort toward a constructive symbiosis of theory and practice is not always without difficulties. A point of friction between theorists and practitioners is often the tendency of the former to question the fundamentals of techniques that are dear to the latter. Two examples are the dependence function metrics and the popular Bochnerian criteria that are discussed below.

The readers may recall that the metric that determines space–time distance affects the mathematical *permissibility* of a dependence model; i.e., a model that is permissible for one metric may be not so for another. Moreover, when dependence models are related through a law or relationship, the permissibility of one of these models may affect that of another. For example, in light of Eq. (5.54) the permissibility of $c_{X;\boldsymbol{p}_i,\boldsymbol{p}_j}$ is affected by that of $c_{Y;\boldsymbol{h},\tau}$. For illustration purposes, consider a covariance of the space–time separable form, $c_{Y;\boldsymbol{h},\tau} = c_{Y;\boldsymbol{h}}\, c_{Y;\tau}$. A general class of mathematical functions that can be associated with (Euclidean or non-Euclidean) metrics is $c_{Y,\boldsymbol{h}} = e^{-N_\mu(\boldsymbol{h})}$, where $N_\mu(\boldsymbol{h}) = \sum_{i=1}^{n} |h_i|^\mu$ and $0<\mu\leqslant 2$ (Christakos and Papanicolaou 2000). Now consider some examples of permissible models. The covariance $c_{Y,\boldsymbol{h}} = e^{-|\boldsymbol{h}|^2}$ is permissible for the Euclidean metric – it is not permissible for the absolute metric (Table 4.1). The covariance

[42] The relevant literature includes (but is not limited to) the following: Serre et al. (2001, 2003a, b), Querido et al. (2007), Tuia et al. (2007), Bogaert and Fasbender (2007), Fasbender et al. (2007), Orton and Lark (2007a, b), Vyas et al. (2004), Bogaert (2002, 2004), Bogaert and Wibrin (2004), Wibrin et al. (2006), Yu et al. (2007a, b,c), Douaik et al. (2004, 2005), Serre and Christakos (1999a, b; 2003), Quilfen et al. (2004), Kolovos et al. (2002), Papantonopoulos and Modis (2006), Akita et al. (2007), Lee et al. (2008a, b, 2009), Bogaert and D'Or (2002), D'Or and Bogaert (2003), Coulliette et al. (2009), Yu and Christakos (2005, 2006), Pang et al. (2009), Puangthongthub et al. (2007), LoBuglio et al. (2007), Choi et al. (2003, 2006, 2007), Savelieva et al. (2005), Parkin et al. (2005), Augustinraj (2002), Law et al. (2006), Wang (2005), Gummer (2009), Kolovos et al. (2010), and de Nazelle et al. (2010).

$c_{Y,\boldsymbol{h}} = e^{-N_1(\boldsymbol{h})}$, on the other hand, is permissible for an absolute (non-Euclidean) metric. The analysis above can be extended to include metrics of the more general form $|\boldsymbol{h}| = (\sum_{i=1}^{n} \lambda_i \, |h_i|^{\mu})^{\mu^{-1}}$, where $1 \leqslant \mu < 2$, and λ_i $(i = 1,...n)$ is a weight determining the "salience" of the h_i-direction. Space–time prediction and mapping depend on the metric structure assumed, since the dependence models are used as inputs in most prediction and mapping techniques. It can be shown, indeed, that the same dataset with its space–time dependence structure represented by covariance models of the same functional form can lead to different space–time predictions and maps, if prediction is performed using different metric structures (Christakos 2000).

In sum, S/TRF modeling allows the evaluation of distinct uncertainty types (conceptual and technical, ontic and epistemic); involves space–time coordinate systems to accommodate different kinds of attribute variability; makes an epistemically sound distinction between general (or core) and specificatory KBs; offers complete system characterization in terms of prediction probability laws (not necessarily Gaussian) at every mapping point (vs. a single prediction at each point); represents heterogeneous dependence patterns and landscapes (rather than artificial curve fitting, ad hoc trend surfaces, etc.); accounts for multiple-point functions representing higher-order spatiotemporal attribute dependencies; and its choice of a coordinate system and associated norm to describe a phenomenon depends on the nature of the properties being described. In fact, metric-dependent analysis of permissibility has important consequences in applications (e.g., space–-time mapping, or the solution of stochastic partial differential equations) in which the investigator is concerned about the validity of space–time dependence functions associated with a physically meaningful metric (Euclidean or non-Euclidean). At this point, let me highlight that so far we have mostly been talking about theoretical space–time dependence models, rather than about their practical counterparts. Often the investigator has to make certain compromises, so to speak, concerning what an adequate and at the same time convenient representation of the theoretical model should be. It is not uncommon in practice, or "practice", that the latter characteristic (convenience) takes precedence over the former (adequacy).

It has been noticed on various occasions that, from a mathematical standpoint, not every function can serve as a spatiotemporal dependence model. Certain formal *permissibility* criteria must be satisfied, which are based on the celebrated Bochner's theorem of positive-definite functions. These criteria – which are valid for spatial and spatiotemporal dependence functions associated with ordinary, generalized, and fractal random fields – are discussed in detail in the relevant literature (Christakos 1984, 1992; Cassiani and Christakos 1998; Christakos and Hristopulos 1998; Christakos et al. 2000; Kolovos et al. 2002). Numerous theoretical and applied studies derive and/or use dependence functions, the validity of which is essentially based on the criterion of Bocherian positive-definiteness (Yaglom 1986; Goodall and Mardia 1994; Jones and Zhang 1997; Ma 2003, 2008, 2009; Fernandez-Casal et al. 2003; Christakos et al. 2005; Stein 2005; Porcu et al. 2008).

It has been said that nothing in "fine print" is ever good news. And the readers should know that there is plenty in "fine print" linked to Bochner's theorem. Certain difficulties with the implementation of the Bochnerian permissibility criteria in practice were identified early on in the spatial analysis literature (Christakos 1984: 257). As it turns out, dependence functions that satisfy these criteria are not necessarily permissible for every random field, even if data analysis seems to associate the dependence function with this field. In the case of covariance functions, the relevant Bochnerian criterion merely guarantees that a Gaussian field exists with the corresponding positive-definite function as its covariance, but it does not necessarily imply that the covariance function is permissible for non-Gaussian fields. Spherical and cosine covariances, e.g., are compatible with the Gaussian law, but not necessarily with the Lognormal probability law. The gist of the whole business is then concentrated in the fact that the Bochnerian limitations briefly mentioned above have potentially serious consequences in real-world applications involving space–-time analysis, attribute prediction, and risk assessment. Unfortunately, such facts are not always explicitly stated in the relevant literature, which makes one look like a character from Akira Kurosawa's 1950 film *Rashomon* who prefers to live a lie than admit the truth. Truth was buried in Rashomon because no one could handle it.

Plato maintained that, "Serious things cannot be understood without laughable things." Which brings us to the curious phenomenon of the so-called "Hamlets of geostatistics." One cannot avoid noticing the unique reasoning style of certain studies characterized by their use of logically inconsistent arguments, and a profound misunderstanding of the theory's fundamental principles. A characteristic example is the paper "To be or not to be. . .stationary? That is the question" (Myers 1989). Despite the paper's title, its author was presumably unaware of Hamlet's misfortunes in the Shakespearean play. *Mutatis mutandis*, the paper's content is almost as troublesome as was Hamlet's situation. Confusion is caused by statements like, "stationarity is not scale related" and "weakly stationary with drift," which involve conflating concepts that need to be distinguished. Incorrect statements that are assumed to be generally applicable include, "variograms are generalized covariances (with a change in sign);" and epistemic notions are mingled with ontic ones (e.g., datasets that are samples from random field realizations vs. datasets that can be represented as a random field realization). There are several contradictory statements, e.g., "stationarity is a property of the random function, not of the data," and a few lines later, "data sets with apparent non-stationarities." What the author also did not know is that in Shakespeare's original play, "when troubles come, they come not as single spies but in battalions."[43] So, conspicuous inaccuracies include statements like, "in Bayesian maximum entropy, it is the posterior distribution for which the entropy is maximized," and that spatial statistics "could be interpreted as including both geostatistics and stochastic modeling" (Myers 2006). In addition, the goal to achieve by definition what one could not achieve by logic or knowledge led to the now famous *locus classicus*: "Generalized functions, i.e., any function that is zero except at one point has a zero integral" (Myers 1993: 408). Laurent Schwartz might turn in his grave if he knew of the above

[43] Shakespeare's *Hamlet* (1603, Act IV, Scene V).

Shakespearean adventures in the mathematical field he pioneered many decades ago. The reason that the above examples are mentioned in this section is instructive: to show why scientists should be prepared to be taught things they know already by "experts" who do not know them. For these self-appointed "experts," understanding an entity is routinely base3d on the confusion between the name of the entity and the entity itself. This leads to nothing less than a gross perversion of technical notions, which are also irrelevant to the issues the "experts" profess to study.

Chapter 6
Stochastic Calculus

It's not where you take things from, it's where you take them to.

Jean-Luc Godard

6.1 Merging Logic and Stochasticity

Stochastic reasoning resembles a spider's web: concentric, firm, transparent, and well spun. This is a web that draws into itself all the conceptual elements of integrative problem-solving (IPS). Ideas and thoughts wing towards it, where metaphors flit through the web to become its nourishment. In the light that it casts on the premises (knowledge bases and the agent's prior mental states), the conclusions (problem-solutions and new findings) begin to glow. In this setting, the prime goal of this chapter is to consider the development of a *stochastic calculus* that is in agreement with the basic conceptual principles of stochastic reasoning discussed in the previous chapter.

6.1.1 Reflections Along the Lakeshore

Said otherwise, the stochastic calculus should be richer than classical (deterministic) logic so that it can account for in situ phenomena under conditions of uncertainty and incorporate the investigator–phenomenon association. This crucial association is based on the investigator's deep involvement and active participation in the representation and interpretation of the phenomenon of interest. To put it in a literary way, the situation would be reminiscent of a man who wanders along the lakeshore and sees reflections on the surface of the water of both himself and the landscape above him.

Within the framework of stochastic calculus, there should be no contradiction between its discursive and intuitive components that should rather form a *unity*. From the outlook enabled by the investigator's creative movement between discursion and intuition, it should become clear that stochastic calculus should be content- and context-dependent. Then, a key issue is whether a calculus should start with

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certain formal probability axioms, and then derive useful results that depend on sound evidential support, probability interpretation, and the doctrine that formal analysis only becomes real on acquiring meaning. But, first we need to introduce into our discussion some fundamental technical concepts and terminology.

6.1.2 From Chrysippus to Frege

Logic operators basically connect the various parts of an argument (sentential, symbolic, or numerical), which is why they are also called connectives and are special cases of the indicator words of Section 5.2. That section introduced the readers to the traditional modes of logic using familiar arguments and examples, and also examined the conceptual transition to stochastic reasoning. In this chapter, we will consider logic operations in terms of S/TRFs (introduced in Section 5.3) together with their associated realizations (possibilities). The readers may find it interesting that connectives (such as "and," "or," and "if, then") were originally introduced by Chrysippus in the third century BC to generate complex sentences.[1] Remarkably, it took almost two millenia until Gottlob Frege recognized the importance of connectives in formal logic, the logic operators or connectives were assigned particular symbols and meaning, and they started playing a fundamental role in the development of modern scientific thought.

6.1.2.1 The Context- and Content-Free Character of Formal Logic

As noted earlier, formal logic operators do not generally account for context and content, but only for the bare knowledge of truth or falsity. Consider any realizations $\chi_{\boldsymbol{p}_i}$ and $\psi_{\boldsymbol{p}_j}$ of the attributes $X_{\boldsymbol{p}}$ and $Y_{\boldsymbol{p}}$ modeled as S/TRFs within the space–time domain $\boldsymbol{p} = (\boldsymbol{s},\ t)$. As is shown in Table 6.1, a number of formal logic operators can be applied on individual realizations leading to composite realizations. Starting with Table 6.1, various combinations of the elementary logic operators can be attempted that lead to more complex $X_{\boldsymbol{p}}$ realizations, such as $\neg(\chi_{\boldsymbol{p}_i} \vee \chi_{\boldsymbol{p}_j})$, meaning that it is not the case that either the first or the second attribute realization materialize in situ; also, $\neg\chi_{\boldsymbol{p}_i} \wedge (\chi_{\boldsymbol{p}_j} \vee \chi_{\boldsymbol{p}_k})$, and $(\chi_{\boldsymbol{p}_i} \rightarrow \chi_{\boldsymbol{p}_j}) \rightarrow \chi_{\boldsymbol{p}_k}$; or composite realizations of different S/TRFs ($X_{\boldsymbol{p}}, Y_{\boldsymbol{p}}, Z_{\boldsymbol{p}}$,...) such as, $\neg(\chi_{\boldsymbol{p}_i} \vee \psi_{\boldsymbol{p}_j})$ and $\neg\chi_{\boldsymbol{p}_i} \wedge (\psi_{\boldsymbol{p}_j} \vee \zeta_{\boldsymbol{p}_k})$. Moreover, following the formal logic of Gottlob Frege to each one of the realizations, the investigator ought to assign one of two truth-values to a realization or a combination of realizations: true (T) or false (F). In other words, the attribute realization $\chi_{\boldsymbol{p}_i}$ either is or is not the case. By combining the truth-values of individual random realizations connected by means of the logic operators, one obtains the truth values of the composite realizations. This is most efficiently expressed by means of the truth-tables that were

[1] A stoic philosopher, Chrysippus has been one of the most significant yet most neglected contributors to logical thinking.

Table 6.1 Logic operators in terms of S/TRF realizations

Logic operator	*Symbol*	*Illustration*	*Meaning*
Negation	$\neg$	$\neg\chi_{p_i}$	Negation of realization χ_{p_i}: χ_{p_i} is not the case
Conjunction	$\wedge$	$\chi_{p_i} \wedge \psi_{p_j}$	Composite realization: both χ_{p_i} and ψ_{p_j} occur
Disjunction	$\vee$	$\chi_{p_i} \vee \psi_{p_j}$	Composite realization: either χ_{p_i} or ψ_{p_j}
Implication	$\rightarrow$	$\chi_{p_i} \rightarrow \psi_{p_j}$	If χ_{p_i} is the case, then ψ_{p_j} is the case. It is not the case that χ_{p_i} and not ψ_{p_j}: $\neg(\chi_{p_i} \wedge \neg\psi_{p_j})$
Equivalence	$\leftrightarrow$	$\chi_{p_i} \leftrightarrow \psi_{p_j}$	χ_{p_i} is the case if and only if ψ_{p_j} is the case. Strong logic operator: $(\chi_{p_i} \rightarrow \psi_{p_j}) \wedge (\psi_{p_j} \rightarrow \chi_{p_i})$
Contradiction	ℓ	$\chi_{p_i} \wedge (\neg\, \chi_{p_i})$	A necessarily false realization
Tautology	τ	$\chi_{p_i} \vee (\neg\, \chi_{p_i})$	A necessarily true realization

Table 6.2 Truth-table of S/TRF realizations

χ_{p_i}	ψ_{p_j}	$\chi_{p_i} \wedge \psi_{p_j}$	$\chi_{p_i} \vee \psi_{p_j}$	$\chi_{p_i} \rightarrow \psi_{p_j}$	$\chi_{p_i} \leftrightarrow \psi_{p_j}$	$\chi_{p_i} \vee (\neg\, \chi_{p_i})$	$\chi_{p_i} \wedge (\neg\, \chi_{p_i})$
T	*T*	*T*	*T*	*T*	*T*	*T*	*F*
T	*F*	*F*	*T*	*F*	*F*	*T*	*F*
F	*T*	*F*	*T*	*T*	*F*	*T*	*F*
F	*F*	*F*	*F*	*T*	*T*	*T*	*F*

originally suggested by Ludwig Wittgenstein. One such table is shown in Table 6.2 in terms of random field realizations. This means that unlike the deterministic (deductive) values of the standard truth-tables, Table 6.2 should be interpreted as referring to the random values (of the realizations) to which suitable probabilities will be assigned later, in which case one may call Table 6.2 a *stochastic truth-table*. A remarkable thing about this kind of tables is that they are constructed using a combination of formal and intuitive considerations.

Take, e.g., the case of "implication" in column 5. For this logic operator, the first two rows of the table capture the intuitively clear patterns that "the truth of ψ_{p_j} follows from that of χ_{p_i}" and that "if the ψ_{p_j} is false and the χ_{p_i} true, then the latter cannot imply the former." However, this is not the case for the remaining two rows that are completed on the basis of formal rather than intuitive considerations – i.e. in the absence of an intuitive truth pattern to go by, these rows are completed in a way that leads to the most useful logic theory. This is a prime feature of formal logic, the epistemic implications of which have not been fully appreciated and investigated. Another feature of formal logic is that it does not contain a mechanism that addresses matters of truth and meaning concerning the premises[2] (Section 5.2). Formal logic merely assumes that the premises are true and then uses rigorous rules to derive perfectly valid conclusions, which, though, may not be physically meaningful if science has not confirmed the truth of the premises. Yet another feature of formal logic is that by taking the truth of the premises for granted, it ignores the

[2] Relevant in this respect is Bohr's comment to Einstein: "You are not thinking, you are merely being logical."

various sources of uncertainty that characterize the in situ phenomena to which these premises refer. Because of the above features, formal logic is characterized as a context- and content-free logic.

Since the consideration of logic operators in a substantive framework and under conditions of uncertainty is not the focus of formal logic, in many in situ cases standard operators and rules of formal logic may need to be modified or even abandoned. A few illustrative examples follow, which emphasize the prime importance of the context within which a physical attribute is considered and of the content of the agent's thinking mode in the case under investigation. Assume that the attribute realizations $\chi_{\boldsymbol{p}_i}$ and $\psi_{\boldsymbol{p}_j}$ refer to an agent's assertions about possible numerical values of the physical attributes $X_{\boldsymbol{p}_i}$ and $Y_{\boldsymbol{p}_j}$. As far as standard logic is concerned, the operators $\chi_{\boldsymbol{p}_i} \wedge \psi_{\boldsymbol{p}_j}$ and $\psi_{\boldsymbol{p}_j} \wedge \chi_{\boldsymbol{p}_i}$ are equivalent. This may not be the case, though, when the substantive knowledge of the situation is accounted for. Let the physical attributes mentioned above obey the law of change $Y_{\boldsymbol{p}_j} = X^2_{\boldsymbol{p}_i}$ (which is part of the G-KB). The operator $(\chi_{\boldsymbol{p}_i} = 2) \wedge (\psi_{\boldsymbol{p}_j} = 4)$ is not necessarily equivalent to $(\psi_{\boldsymbol{p}_j} = 4) \wedge (\chi_{\boldsymbol{p}_i} = 2)$. In the former operator, if $\chi_{\boldsymbol{p}_i} = 2$, then $\psi_{\boldsymbol{p}_j} = 4$ (in light of the physical law). This is not so, however, in the case of the latter operator, since given that $\psi_{\boldsymbol{p}_j} = 4,$ both realizations $\chi_{\boldsymbol{p}_i} = 2$ and $\chi_{\boldsymbol{p}_i} = -2$ are possible according to the physical law. Otherwise said, both operators $(\psi_{\boldsymbol{p}_j} = 4) \wedge (\chi_{\boldsymbol{p}_i} = 2)$ and $(\psi_{\boldsymbol{p}_j} = 4) \wedge (\chi_{\boldsymbol{p}_i} = -2)$ could occur. Last but not the least, assume that the attribute realizations $\chi_{\boldsymbol{p}_i}$ $\psi_{\boldsymbol{p}_i}$, and $\zeta_{\boldsymbol{p}_i}$ occur in an everyday life environment. In this context, the following distributive rule of classical logic is formally valid, $\chi_{\boldsymbol{p}_i} \wedge (\psi_{\boldsymbol{p}_i} \vee \zeta_{\boldsymbol{p}_i}) = (\chi_{\boldsymbol{p}_i} \wedge \psi_{\boldsymbol{p}_i}) \vee (\chi_{\boldsymbol{p}_i} \wedge \zeta_{\boldsymbol{p}_i})$. In the microscopic (subatomic) world, however, the above rule is not valid. Hence, when the substantive features of the physical mechanisms underlying the attribute possibilities of interest are taken into account, certain rules of classical logic may not be meaningful, and should be revised in the stochastic reasoning setting.

6.1.2.2 Russell and Putnam Enter the Scene

A little history of logic is appropriate at this point. Russell remarked that logic has to be made sensitive to the grammar of the sentence, whereas Donald Davidson's perspective was that one knows how to use a sentence, if one knows the real conditions under which the sentence is true (Davidson 1967). Frege suggested the so-called *context principle*: one knows the meaning of the words that compose a sentence only within the context of the sentence as a whole. In a similar manner, concepts, notions, and terms obtain their proper meaning in the setting of the in situ problem. One may feel hot, e.g., due to the weather or due to sickness, which are two very different things. Furthermore, under certain conditions, the algebraic properties of logic may be susceptible to revision on empirical grounds.[3] One of the proponents of this idea was Hilary Putnam (1968), who drew an interesting analogy between the

[3] Such is the case of quantum systems proposed by Garrett Birkhoff, John von Neumann, and Hilary Putnam, among others.

principles of logic and those of geometry: while for almost 2,000 years the Euclidean geometry was considered rational knowledge (its postulates were identified as truths of reason), the findings of modern physics (Einstein's theory of relativity) showed geometry to be rather empirical knowledge, i.e. depending on one's experience. And this is also the case with logic, according to Putnam.

Stochastic reasoning and the associated calculus make an attempt to address the above and similar limitations of formal logic in the context of the S/TRF theory that represents natural attributes under conditions of uncertainty and spatiotemporal variation.[4] This is the focus of the following sections.

6.1.3 The Substantive Character of Stochastic Calculus

Let us take stock: logic is the science of reason, not of truth, in addition to reason one needs empirical facts. As far as stochastic reasoning is concerned, the concepts and principles of logic used in IPS should have a strong substantive character; they should account for the content of the agent's thinking style and the context of the natural system under investigation. This is hardly a novel way of looking at things in epistemology, although it is new in the science-based S/TRF context where it gains some interesting and rather unexpected insights. As noted earlier, many thinkers have considered the idea of context- and content-dependent logic. In this book, however, stochastic reasoning is concerned with natural phenomena that vary across space–time and are modeled as STRFs, and it seeks to develop a stochastic calculus (with its metalanguage and interpretive rules) to study such phenomena in a systematic and physically meaningful manner. Correspondingly, stochastic calculus postulates that by cultivating the interdependence between stochastics and logic could provide a key to realizing the potency of each field in its distinctive contribution to IPS.

6.1.3.1 Content- and Context-Dependency of Stochastic Calculus

Let us revisit Tables 6.1 and 6.2. Stochastic calculus is living experience mathematics (Section 3.1.1) that accounts for the three "–isms" of science: *naturalism*, *theorism* and *empiricism*. Otherwise said, stochastic calculus investigates aspects of Nature based on scientific theories that are empirically verifiable. This means that, unlike standard logic, stochastic reasoning is concerned with issues such as whether science can confirm the content- and context-dependent truth of the premises, how laws of change may connect the premises with the conclusion, and how to account for the uncertainty conditions characterizing the in situ context of the premises. Clearly, a standard operator defined solely in terms of truth and falsity is too narrow to fully capture the causality features of the in

[4] The readers may recall that uncertainty is linked to the epistemic condition of the investigator, whereas variability is a physical characteristic of the attribute.

situ phenomenon. For a stochastic operator the columns and rows of truth-tables should be filled in a substantive manner that accounts for the in situ phenomenon under conditions of uncertainty. For example, in stochastic reasoning the operator $\chi_{\boldsymbol{p}_i} \wedge \chi_{\boldsymbol{p}_j}$ (Table 6.2) will consider the occurrence of both attribute realizations $\chi_{\boldsymbol{p}_i}$ and $\chi_{\boldsymbol{p}_j}$ only if these two realizations are not just formally but also contentually (physically) consistent in the space–time context. Equally important, the logic operators (Table 6.1) do not merely have a symbolic form but are linked to a metalanguage, which implies that some of the operators (e.g., $\neg$, $\wedge$, and $\vee$) are used to generate new possibilities, whereas some others (e.g., $\rightarrow$ and $\leftrightarrow$) are used to express the existing relationships between possibilities.

These considerations entail, *inter alia*, that the underlying natural laws should equip logic operators with stochastic causality features.[5] This means that, while in standard logic an implication is considered valid even if two attributes are contentually irrelevant,[6] stochastic reasoning avoids such pitfalls because it considers entities that are linked via a law of change and, hence, they are contentually relevant. For illustration, let the numerical possibilities $\chi_{\boldsymbol{p}_i}$ and $\chi_{\boldsymbol{p}_j}$ denote an agent's assertions (via observation, experimentation, introspection, etc.) of the values of pollutant concentration $X_{\boldsymbol{p}}$ at space–time points with coordinates $\boldsymbol{p}_i = (\boldsymbol{s}_i, t_i)$, $\boldsymbol{p}_j = (\boldsymbol{s}_j, t_j)$. Also assume that the underlying physical law of change is $X_{\boldsymbol{p}_j} = X_{\boldsymbol{p}_i} e^{\beta|\boldsymbol{p}_j - \boldsymbol{p}_i|}$, which relates causally the chemical concentrations at points $\boldsymbol{p}_i$ and $\boldsymbol{p}_j$, and β is an empirical parameter. For a $\chi_{\boldsymbol{p}_i}$ value at $\boldsymbol{p}_i$, the law contentually assigns a $\chi_{\boldsymbol{p}_j}$ value at $\boldsymbol{p}_j$, and vice versa. In this sense, the concentration values at $\boldsymbol{p}_i$ and $\boldsymbol{p}_j$ may be linked using physically meaningful logic operators that express the existing relationships between possibilities (e.g., $\rightarrow$ and $\leftrightarrow$). In stochastic calculus, the probability assessments involve a metalanguage that is not definite but rather conditioned on the knowledge available to the rational investigator (Section 4.4.6). The readers may recall that in the stochastic reasoning milieu, the investigator's assertion about an attribute $X_{\boldsymbol{p}}$ is mediated by the investigator's understanding of what $X_{\boldsymbol{p}}$ is. At the same time, the observations are *focused* (on aspects of investigator's interest) rather than passive. In general, the investigators can assign probabilities to their assertions about any uncertain realization resulting from the application of logic operators. In symbolic terms, one can assign composite probabilities to any function of the attributes $X_{\boldsymbol{p}}$, $Y_{\boldsymbol{p}}$, $Z_{\boldsymbol{p}}$,...; i.e.

$$\text{If } \Xi_{XYZ\ldots} = \Xi_{XYZ\ldots}(\chi_{\boldsymbol{p}_i},\ \psi_{\boldsymbol{p}_j},\ \zeta_{\boldsymbol{p}_k}, \ldots), \quad \text{then } P_{KB}[\Xi_{XYZ\ldots}] = \beta, \tag{6.1}$$

where the β varies between 0 and 1. Accordingly, standard truth-tables are replaced by stochastic tables, like Table 6.3: the two values, T and F, have been replaced by an infinite range of possible values between 0 and 1 that provide an assessment of the

[5] In fact, it is a fundamental ontic principle that the values of every essential natural attribute in space-time are lawfully related to each other.

[6] Section 1.2.3 already stressed that the formal logic paradox that $\chi_{\boldsymbol{p}_i} \rightarrow \chi_{\boldsymbol{p}_j}$ is valid, even if the $\chi_{\boldsymbol{p}_i}$ and $\chi_{\boldsymbol{p}_j}$ are contentually irrelevant, which can lead to counter-intuitive results.

Table 6.3 Realization probabilities associated with the logic operators of Table 6.2

$P_{KB}[\chi_{p_i}]$	$P_{KB}[\psi_{p_j}]$	$P_{KB}[\chi_{p_i} \wedge \psi_{p_j}]$	$P_{KB}[\chi_{p_i} \vee \psi_{p_j}]$
[0, 1]	[0, 1]	[0, 1]	[0, 1]
$P_{KB}[\chi_{p_i} \to \psi_{p_j}]$	$P_{KB}[\chi_{p_i} \leftrightarrow \psi_{p_j}]$	$P_{KB}[\chi_{p_i} \vee (\neg\chi_{p_i})]$	$P_{KB}[\chi_{p_i} \wedge (\neg\chi_{p_i})]$
[0, 1]	[0, 1]	1	0

relative truthfulness or falsehood of the corresponding attribute values (e.g., $P_{KB}[\chi_{p_i}] = 0.3$). Arguably, Table 6.3 is a much more reasonable representation of real-world situations than a standard truth-table. In Table 6.3, the calculation of the probable values of the composite possibilities is closely linked with the probable values of individual possibilities as determined by the real-world conditions, the form of the logic operator considered, and the agents' epistemic situation. Let us assume, e.g., $P_{KB}[\chi_{p_i}] = 0.3$. If the agent possesses the concept of conjunction $\chi_{p_i} \wedge \psi_{p_j}$, he must be able to make the transition from the contents of χ_{p_i} and ψ_{p_j} to the content of $\chi_{p_i} \wedge \psi_{p_j}$ and assign a meaningful probability to it, say, $P_{KB}[\chi_{p_i} \wedge \psi_{p_j}] = 0.2$. Then, $P_{KB}[\chi_{p_i} \to \psi_{p_j}] = 0.9$ (see Eq. (6.6)). That is, the probability that *Agent's assertion about* $X_{p_i} = \chi_{p_i}$ *implies the assertion about* $Y_{p_j} = \psi_{p_j}$ *in light of the KB available is* 0.9 (also, Section 1.2.3.4). The stochastic metalanguage acknowledges an indissoluble unity of the investigator's own experience and the in situ attributes, *de la vie et du vécu*,[7] as the relational medium within which probabilities emerge. In view of Eq. (6.1), stochastic reasoning takes advantage of commonly used tricks in developing probabilistic tables that bring the composite realization (possibility) in a simpler form, so that the corresponding probabilities are easily calculated with the help of the above rules and tables. Consider two special cases: the $\Xi_X = \chi_{p_i} \wedge (\neg\, \chi_{p_i})$ can be replaced by $\Xi_X = \ell$, in which case, $P_{KB}[\Xi_X] = P_{KB}[\ell] = 0$. That is, if a realization is a contradiction, it has zero probability. In an analogous manner, $\Xi_X = \chi_{p_i} \vee (\neg\, \chi_{p_i})$ is replaced by $\Xi_X = \tau$, so that $P_{KB}[\Xi_X] = P_{KB}[\tau] = 1$. That is, if an attribute realization is a tautology (an all true, *T*, column in the truth-table), it has probability 1.

Just as was the case with stochastic logic operators, the associated probabilities must be content- and context-sensitive too. In the context of the Fermi–Dirac model, e.g., statistical probabilities apply to different particles (e.g., electrons), in the Bose–Einstein theory probabilities apply to some particles (e.g., photons) and not to others, and Maxwell–Boltzmann statistics do not apply to any known particles. The readers may recall (Section 4.3) that an objective consideration of probability priors is to view them as natural entities obtained on the basis of experience. Accordingly, the derivation of these priors requires a reasonable understanding of what agents know and how they learn it – this is a process that involves psychological and cognitive sciences.[8]

[7] Of life and the lived.

[8] The readers may recall from Chapter 3, that it is one thing to scientifically describe the processes that make human agents what they are, and another thing to describe what it is like for an agent to live life (e.g., describe the nature and contents of one's experience).

A telling point is that the content of a scientific hypothesis depends on the language in which it is stated, and the same may be true for the probability attached to the hypothesis. In addition, scientific progress often brings with it a change in the content and context of scientific statements and theories (e.g., new concepts are added, and new meanings are given to old notions), and as a result it can also change the meaning of the relevant probabilities. These requirements exclude probability interpretations that are otherwise formally valid. Assume, e.g., that the probability P_{KB} is interpreted as the truth function; i.e. it can take two values, $P_{KB}[\chi_{\boldsymbol{p}}\text{ is }T] = 1$ and $P_{KB}[\chi_{\boldsymbol{p}}\text{ is }F] = 0$. This P_{KB} trivially satisfies Kolmogorov's axioms (Section 4.4.3.1), i.e. it is formally admissible. It is not, however, a sound interpretation since by not taking intermediate values (between 0 and 1), the truth function P_{KB} cannot accommodate the variety of content- and context-dependent probability assertions routinely made by a rational agent about in situ phenomena under conditions of uncertainty. Indeed, the evidential context of experimental measurements and/or the physical content of scientific theories (such as those mentioned earlier) require that probability values between 0 and 1 should be allowed (in the experimental context of quantum mechanics, even irrational-valued probabilities are observed). Lastly, let me share with you a historical tale amusing and clever enough that may charm even ahistorical readers. When Socrates was asked by Arhidamus, one of his students, whether he should marry or not, the great man answered: "By all means, yes. If you get a good wife, you will become a happy man; if you get a bad wife, you will become a philosopher." In view of Socrates' thoughts about marriage, let us approach the matter in terms of the possibilities: $\chi = \textit{Arhidamus and Iokaste got married}$, and $\psi = \textit{Iokaste got pregnant}$. From a standard logic viewpoint, the possibilities $\chi \wedge \psi$ and $\psi \wedge \chi$ are equivalent,[9] in which case $P_{KB}[\chi \wedge \psi] = P_{KB}[\psi \wedge \chi]$. However, this may not be true when the meaning of each logic operator is considered in the physical time context ($t_i < t_j$). Given the existence of physical time, the $\chi_{t_i} \wedge \psi_{t_j}$ in the above example has a different meaning than $\psi_{t_i} \wedge \chi_{t_j}$, in which case it is possible that $P_{KB}[\chi_{t_i} \wedge \psi_{t_j}] \neq P_{KB}[\psi_{t_i} \wedge \chi_{t_j}]$.[10] Otherwise said, the probability of "Arhidamus and Iokaste got married and then Iokaste got pregnant" may be different than the probability of "Iokaste got pregnant and then she got married with Arhidamus." Hence, physical time is linked to the meaning of a logic operator, whereas the direct implementation of standard logic may miss this point. To put it in different words, stochastic reasoning appreciates the fact that agents operate in an open system.

A careful look could reveal some interpretational and other differences of stochastic reasoning and standard logic. In stochastic reasoning, an entity and its negation are both possible in the sense that they have complementary probabilities, $P_{KB}[\neg\chi_{\boldsymbol{p}}] = 1 - P_{KB}[\chi_{\boldsymbol{p}}]$. The readers may notice that this is essentially a stochastic version of classic logic's law of excluded middle.[11] The stochastic version of the law – in which both entities $P_{KB}[\chi_{\boldsymbol{p}}]$ and $P_{KB}[\neg\chi_{\boldsymbol{p}}]$ may exist – seems to violate the essence

[9] I.e., they have the same truth-value.

[10] I.e., they may have different truth-values.

[11] Aristotle's law of excluded middle: $\chi_{\boldsymbol{p}} \vee (\neg\chi_{\boldsymbol{p}})$; i.e., every $\chi_{\boldsymbol{p}}$ is either valid or is not.

of the standard law, according to which if the entity χ_p is valid, $\neg\chi_p$ cannot be true, and vice versa. Similarly, one can calculate the $P_{KB}[\neg(\chi_p \wedge (\neg\chi_p))]$, which means that the standard interpretation of the law of noncontradiction[12] may be not the same in the stochastic setting. Also, the readers should have no difficulty to notice that the *many-valued* logic (also known as *fuzzy* logic) can be readily considered in the stochastic reasoning framework.

Last but not least, the importance of assigning proper meaning to formal constructs has been stressed out in several parts of the book. The highly influential truth-conditional theory of meaning argues that the meaning of an entity (proposition, sentence, attribute, representation etc.) is given by stating the conditions under which it is true (Lehrer and Lehrer, 1970). This theory has been opposed on the basis that it requires that declarative sentences all be determinately true or false whether an agent knows it for sure, thus often putting what is required for grasp of meaning beyond an agent's epistemic powers (Grayling, 2010). The meaning assigned to the relevant notions by stochastic reasoning deals with this situation by replacing "deterministic truth or falsity" with "probabilistic truth or falsity" (see, e.g., Table 6.3). Then, the meaning of an entity may be given by describing the conditions with the associated uncertainty under which it may be true with a specified probability.

6.1.4 Deduction as a Component of Stochastic Reasoning

Stochastic reasoning improves practical inference by reconsidering deduction in a novel and more realistic setting. Some readers may find it surprising, since probability is associated with induction, whereas deduction is considered a deterministic process. Nevertheless, one of the advantages of stochastic reasoning is that by acknowledging the uncertainties of in situ phenomena, it formulates deduction in a way that accounts for these uncertainties.

Stochastic reasoning maintains that in many situations of in situ uncertainty, deductive analysis in its stochastic form may be particularly useful. Let us consider the composite operators $\Xi_{XYZ\ldots}$ and $\Xi'_{XYZ\ldots}$. If these operators are logically equivalent, then they have equal uncertainties (or probabilities), i.e.

$$\text{If } \Xi_{XYZ\ldots} \leftrightarrow \Xi'_{XYZ\ldots}, \quad \text{then } U_{KB}[\Xi_{XYZ\ldots}] = U_{KB}[\Xi'_{XYZ\ldots}], \tag{6.2}$$

where U_{KB} denotes the uncertainty of the agent's assertion concerning the $\Xi_{XYZ\ldots}$ and $\Xi'_{XYZ\ldots}$.[13] For example, the composite realization $\chi_{p_j} \wedge (\chi_{p_i} \vee (\neg\, \chi_{p_i}))$ is

[12] Aristotle's law of non-contradiction: $\neg(\chi_p \wedge (\neg\chi_p))$.

[13] As we will see in Section 6.2.3, in certain in situ situations there are some reasons that favor the use of the uncertainty concept instead of the probability one.

Table 6.4 Truth-table for the composite S? TRF realization $\chi_{p_j} \wedge (\chi_{p_i} \vee (\neg\, \chi_{p_i}))$

χ_{p_i}	χ_{p_j}	$\neg\, \chi_{p_i}$	$\chi_{p_i} \vee (\neg\, \chi_{p_i})$	$\chi_{p_j} \wedge (\chi_{p_i} \vee (\neg\, \chi_{p_i}))$
T	*T*	*F*	*T*	*T*
T	*F*	*F*	*T*	*F*
F	*T*	*T*	*T*	*T*
F	*F*	*T*	*T*	*F*

logically equivalent to the simple realization χ_{p_j} (Table 6.4) and hence, $U_{KB}[\chi_{p_j} \wedge (\chi_{p_i} \vee (\neg\, \chi_{p_i}))] = U_{KB}[\chi_{p_j}]$. In a similar manner, it can be shown that $\chi_{p_i} \leftrightarrow (\chi_{p_i} \wedge \chi_{p_j}) \vee (\chi_{p_i} \wedge (\neg\, \chi_{p_j}))$, and $(\chi_{p_i} \wedge (\neg\, \chi_{p_j})) \vee \chi_{p_j} \leftrightarrow \chi_{p_i} \vee \chi_{p_j}$. Now consider the case of two operators that are mutually exclusive:

$$\begin{aligned} \text{If } \Xi_{XYZ\ldots} \wedge \Xi'_{XYZ\ldots} \leftrightarrow \ell, \text{then } & U_{KB}[\Xi_{XYZ\ldots} \vee \Xi'_{XYZ\ldots}] \\ &= U_{KB}[\Xi_{XYZ\ldots}] + U_{KB}[\Xi'_{XYZ\ldots}] - 1, \end{aligned} \tag{6.3}$$

or equivalently, the probability of their disjunction is the sum of their individual probabilities. For example, if the attribute realizations χ_{p_i} and $\neg\, \chi_{p_i}$ are mutually exclusive, i.e. $\chi_{p_i} \wedge (\neg\, \chi_{p_i}) \leftrightarrow \ell$, then $U_{KB}[\chi_{p_i} \vee (\neg\, \chi_{p_i})] = U_{KB}[\chi_{p_i}] + U_{KB}[\neg\, \chi_{p_i}] - 1$. The readers may want to check the validity of $U_{KB}[(\chi_{p_i} \wedge \chi_{p_j}) \wedge (\chi_{p_i} \wedge (\neg\, \chi_{p_j}))] = U_{KB}[(\chi_{p_i} \wedge \chi_{p_j})] + U_{KB}[\chi_{p_i} \wedge (\neg\, \chi_{p_j})] - 1$.[14] Lastly, the following is an important general inference:

$$\text{If } \Xi_{XYZ\ldots} \therefore \Xi'_{XYZ\ldots}, \text{then } U_{KB}[\Xi'_{XYZ\ldots}] \leq U_{KB}[\Xi_{XYZ\ldots}]. \tag{6.4}$$

Two elementary examples follow. Suppose that $\Xi_X = \chi_{p_i}$ and $\Xi'_{XY} = \chi_{p_i} \vee \psi_{p_j}$. Since $\chi_{p_i} \therefore (\chi_{p_i} \vee \psi_{p_j})$, it is valid that $U_{KB}[\chi_{p_i} \vee \psi_{p_j}] \leq U_{KB}[\chi_{p_i}]$. Let $\Xi_{XY} = \chi_{p_i} \wedge \psi_{p_j}$, $\Xi_Y = \psi_{p_j}$. Since $\chi_{p_i} \wedge \psi_{p_j} \therefore \psi_{p_j}$, it is valid that $U_{KB}[\psi_{p_j}] \leq U_{KB}[\chi_{p_i} \wedge \psi_{p_j}]$. In light of developments in Section 4.5.1, the result can be generalized: If $(\Xi_{XYZ\ldots} = \chi_{p_i} \wedge \psi_{p_j} \wedge \zeta_{p_k} \ldots) \therefore (\Xi'_W = \omega_{p_q})$, then $U_{KB}[\omega_{p_q}] \leq U_{KB}[\chi_{p_i} \wedge \psi_{p_j} \wedge \zeta_{p_k} \ldots] \leq U_{KB}[\chi_{p_i}] + U_{KB}[\psi_{p_j}] + U_{KB}[\zeta_{p_k}] + \ldots$

A useful implementation of Eq. (6.4) is as follows: To demonstrate that an inference is not valid, an investigator only needs to show that the corresponding uncertainty inequality does not hold. In other words, if $\Xi_{XYZ\ldots} \therefore \Xi'_{XYZ\ldots}$, then it is necessarily true that $U_{KB}[\Xi'_{XYZ\ldots}] \leq U_{KB}[\Xi_{XYZ\ldots}]$. If, however, it could be shown that $U_{KB}[\Xi'_{XYZ\ldots}] > U_{KB}[\Xi_{XYZ\ldots}]$, then the inference $\Xi_{XYZ\ldots} \therefore \Xi'_{XYZ\ldots}$ will not be valid. If, on the other hand, the inequality is true, then the inference is probably valid (in the stochastic sense). For illustration, consider the inference: If $\psi_{p_j} \therefore \chi_{p_i} \rightarrow \psi_{p_j}$, then

[14] Hint: Start from $(\chi_{p_i} \wedge \chi_{p_j}) \wedge (\chi_{p_i} \wedge (\neg\, \chi_{p_j})) \leftrightarrow \ell$.

$U_{KB}[\chi_{p_i} \to \psi_{p_j}] \leq U_{KB}[\psi_{p_j}]$. The last uncertainty inequality is equivalent to the valid probabilistic inequality $P_{KB}[\psi_{p_j}] \leq P_{KB}[\chi_{p_i} \to \psi_{p_j}]$ and, hence, the inference is probably valid in a stochastic sense. Using the same line of thought, Table 6.5 presents the uncertainty inequalities associated with the standard deduction rules of Table 5.3. One must keep in mind that while the standard rules assume complete certainty, the stochastic rules take into account the uncertainty characterizing the in situ conditions of the phenomenon. For illustration, let us examine the case of stochastic *modus tollens* inference in Table 6.5. The associated inequality $U_{KB}[\neg\chi_{p_i}] \leq U_{KB}[\chi_{p_i} \to \psi_{p_j}] + U_{KB}[\neg\psi_{p_j}]$ is true, since it is equivalent to the valid probabilistic inequality $P_{KB}[\chi_{p_i} \to \psi_{p_j}] \leq 1 - P_{KB}[\chi_{p_i}] + P_{KB}[\psi_{p_j}]$. Therefore, the stochastic *modus tollens* is a valid inference. The readers may want to check the validity of the other inequalities in Table 6.5. Next, let us consider the natural attribute represented by the S/TRF $X_{\boldsymbol{p}}$ that obeys the physical law $\chi_{p_j} = \phi(\chi_{p_i})$, where $\phi(\cdot)$ is an one-to-one function (see Section 4.4.7). In view of the preceding analysis, if $\chi_{p_j} = \phi(\chi_{p_i}) \therefore (\chi_{p_i} \to \chi_{p_j})$, then it is necessary that $U_{KB}[\chi_{p_i} \to \chi_{p_j}] \leq U_{KB}[\chi_{p_j} = \phi(\chi_{p_i})]$. The last inequality is, indeed, correct since it is equivalent to the probability inequality Eq. (6.23) of Table 6.6. Therefore, the inference that such a physical law entails the material implication is valid in a stochastic sense. Obviously, the inverse inference is not necessarily true. The readers could also use stochastic truth-tables to confirm these results. The above is a simple demonstration of the fact that stochastic calculus links logic operators to natural laws, thus viewing them as substantively well-grounded mental constructs. Otherwise said, stochastic calculus is the principal language in which to express natural laws under conditions of uncertainty; and also a suitable mathematical tool with which to explore them further. Correspondingly, stochastic reasoning suggests a fundamental symbiosis of natural laws and logic in the form of an integrated whole that reconciles the world

Table 6.5 Uncertainty inequalities associated with deduction rules in a stochastic context

Modus tollens $U_{KB}[\neg\chi_{p_i}] \leq U_{KB}[\chi_{p_i} \to \psi_{p_j}] + U_{KB}[\neg\psi_{p_j}]$	*Modus ponens* $U_{KB}[\psi_{p_j}] \leq U_{KB}[\chi_{p_i} \to \psi_{p_j}] + U_{KB}[\chi_{p_i}]$
Simplification $U_{KB}[\chi_{p_i}] \leq U_{KB}[\chi_{p_i} \wedge \psi_{p_j}]$	*Conjunction* $U_{KB}[\chi_{p_i} \wedge \psi_{p_j}] \leq U_{KB}[\chi_{p_i}] + U_{KB}[\psi_{p_j}]$
Absorption $U_{KB}[\chi_{p_i} \to (\chi_{p_i} \wedge \psi_{p_j})] \leq U_{KB}[\chi_{p_i} \to \psi_{p_j}]$	*Excluded middle* $U_{KB}[\psi_{p_j}] \leq U_{KB}[\chi_{p_i} \to \psi_{p_j}] + U_{KB}[\neg\chi_{p_i} \to \psi_{p_j}]$
Disjunctive syllogism $U_{KB}[\psi_{p_j}] \leq U_{KB}[\chi_{p_i} \vee \psi_{p_j}] + U_{KB}[\neg\chi_{p_i}]$	*Constructive dilemma* $U_{KB}[\zeta_{p_k} \vee \omega_{p_q}] \leq U_{KB}[\chi_{p_i} \vee \psi_{p_j}] +$ $U_{KB}[(\chi_{p_i} \to \zeta_{p_k}) \wedge (\psi_{p_j} \to \omega_{p_q})]$
Contradiction $U_{KB}[\neg\chi_{p_i}] \leq U_{KB}[\chi_{p_i} \to \psi_{p_j}] +$ $U_{KB}[\chi_{p_i} \to \neg\psi_{p_j}]$	*Addition* $U_{KB}[\chi_{p_i} \vee \psi_{p_j}] \leq U_{KB}[\chi_{p_i}]$
Hypothetical syllogism $U_{KB}[\chi_{p_i} \to \omega_{p_m}] \leq U_{KB}[\chi_{p_i} \to \psi_{p_j}] +$ $U_{KB}[\psi_{p_j} \to \zeta_{p_k}] + \ldots + U_{KB}[\upsilon_{p_q} \to \omega_{p_m}]$	*Direct generalization* $U_{KB}[\langle \Theta \mid \chi_{\boldsymbol{p}} \rangle] \leq U_{KB}[\chi_{\boldsymbol{p}} \in X_{\boldsymbol{p}}] + U_{KB}[\langle \Theta \mid X_{\boldsymbol{p}} \rangle]$

of meaning with the world of science. To consider a physical law is at the same time to establish this law in thought and language, to incorporate it into a pre-existing worldview. At this point the readers are reminded that the "logic-natural law" is the second symbiosis assumed by stochastic reasoning. Section 5.2.2.2 already suggested that, in the stochastic reasoning milieu, logic and psychology mutually constrain each other in an analogous way that mathematics and physical science constrain each other.

6.1.5 Stochastic Falsification Principle

The analysis above implies that several well-known results could be reconsidered under the light of stochastic reasoning. For example, let us examine Popper's falsification principle (Section 1.1.2.3) in a stochastic context. Assume, as usual, that M_X denotes a physical law and that χ_p are the predictions of the attribute X_p made by this law. One can write, $M_X \to \chi_p$, which means that "if M_X is a valid physical law, then its prediction χ_p will occur." Falsification essentially requires that one must search for one χ_p that does not satisfy the implication $M_X \to \chi_p$. This may require one to check too many possible predictions χ_p. However, since in the real-world there is a level of uncertainty associated with both M_X and χ_p, one only needs to consider a stochastic version of the falsification principle.

One way to do this is to consider the validity of the MC probability $P_{KB}[M_X \to \chi_p]>>$[15] for all possible χ_p. In logic terms, the $M_X \to \chi_p$ is equivalent to $\neg(M_X \wedge (\neg\chi_p))$, which means that $P_{KB}[M_X \to \chi_p] = P_{KB}[\neg(M_X \wedge (\neg\chi_p))]$. The key point here is that in practice it is easier to check the validity of $P_{KB}[\neg(M_X \wedge (\neg\chi_p))]>>$ than that of $P_{KB}[M_X \to \chi_p]>>$. Indeed, one needs to check the validity of the latter probability statement for all possible attributes χ_p, whereas the former probability statement requires just one χ_p for which the probability $P_{KB}[\neg(M_X \wedge (\neg\chi_p))]$ is not significantly large in order to consider rejecting the law M_X.

6.1.6 Reasoning with Shadow Statements, and Esprit de Finesse[16]

Due to the interdisciplinary nature of IPS, the investigators should pay sufficient attention to the sociological forces that bound the participating groups to their paradigms (which includes scientists, politicians, and managers). The reality of sociopolitical life often makes it necessary to assign truth-values to various shadow statements (statements made in the context of shadow epistemology; Section 1.4). In many cases, these are wittingly untruthful or willfully ignorant statements, which means that one should be careful when assigning probabilities to shadow statements

[15] The symbols "$>>$" and "$<<$" mean considerably large and considerably small, respectively.
[16] Mental finesse.

and then using them in decision-making, because they may lead to incorrect evaluation of the in situ situation with possibly severe consequences.

One can find shadow statements not only in politics, economics, and the media, but also in the sciences when the stakes are high. For illustration purposes, assume that the $X_{p;i}$, $i = 1, ..., m$, are physical attributes related to the environmental hazard condition of a region during a specified time period, and the Z_p is the corresponding population health effect resulting from $X_{p;i}$. Consider the case of a wittingly untruthful pollution exposure assessment, say $X_{p;1} = \chi_{p;1} < v$, where v is a threshold that should not be exceeded. Because of the complicated physical and biological laws governing the above attributes, it is possible that regardless of the very low probability $P_{KB}[\chi_{p;1} < v] = \eta_0 <<$ one may assign to the false assessment about $X_{p;1}$, the probability that a false health effect, say $Z_p < \zeta_p$, is obtained from the propagation of η_0 via these laws, can be very high, i.e. $P_{KB}[Z_p < \zeta_p] = \eta_F >>$. This result can lead to wrong and potentially harmful conclusions about the population health situation. Said otherwise, a shadow statement about a physical attribute that initially seems to be harmless (owing to its very low probability of occurrence, etc.), when combined with other scientific statements via the corresponding natural laws and exposure-health associations, could have severe population health consequences.

Putting shadow epistemology and its consequences aside for a moment, let us conclude this section with a few positive thoughts. As a mental construct, stochastic reasoning is not uniquely linked to an unknown reality out there. Rather, it is a conceptual net that the investigator casts over the chaotic maze of so-called reality, constantly open to challenge by the uncertainty that characterizes one's own experience of the manifold of reality. On the one hand, the net's capability is rooted in the investigator's own attainment of a proper balance between rational thought and intuition. To quote Einstein, "The intuitive mind is a sacred gift and the rational mind is a faithful servant. We have created a society that honors the servant and has forgotten the gift." On the other hand, the investigator's experience with the in situ phenomenon is not a primal experience of the phenomenon itself, nor is merely a re-experiencing of it. It is rather an experience that forms itself on account of the investigator's cognitive condition and pre-existing worldview. One of the things the above considerations infer is that intuition derived from contemplative thinking and deep understanding of the problem at hand plays an important role in guiding stochastic theorists in their analytical calculations. This is what Blaise Pascal called *esprit de finesse*, i.e. a sort of "insightful understanding" based on self-cultivation, inwardness, and interpenetration. Which is why certain theorists are able to correctly anticipate complex solutions and results based on their instincts about the problem. In doing so, they often assume a guru-like status in their field of expertise. Last but not least, mental finesse invokes the generation of new and important ideas, which every field of inquiry needs in order to flourish. The value of a new idea or a thought is measured in terms of its distance from the continuity of the familiar. The smaller this distance is, the smaller the value of the idea or thought, and the higher the chances that the idea or thought will succumb to repetition and banality. As far as IPS scientists are concerned, their real-world experience enables them to think creatively within the stochastic reasoning setting, because they are not forced to consider throwing dice or making bets as prototypical situations in which uncertainty arises. For example, an environmental expert assessing different physico-chemical techniques of measuring pollution and a physician evaluating disease symptoms are both conceptually far from throwing dice or making bets.

6.2 Probability Evolution: Conditionals as Quantified Adaptation

Within the context of the present discourse, Epibraimatics views probability conditionals in terms of quantified *adaptation*. Section 3.5.4 characterized adaptation as a basic mental function that represented an equally important brain activity. Brain's interaction with the environment (including the continuous feedback the former gets from the latter) plays a decisive role in the selection of a design that resolves in an efficient manner the adaption issue. This reflects, in a sense, the Darwinian insight that there should be a functional relationship between the brain activity and the adaptation issue to be resolved within the environment in which it evolves. Depending on the problem of interest, there should be a certain flexibility concerning the design selection.

6.2.1 The Horse Before the Cart

A similar flexibility should characterize the investigator's choice of the probability *conditional* that quantifies the adaptation postulate (AP of Section 3.5.4) as part of the IPS process. The changing environment may correspond to the varying cognitive conditions and the potential differences between the knowledge sources emerging during the process. Feedback provided by these sources defines the problem's features the probability conditional has to account for. If new knowledge emerges (e.g., a set of site-specific data) that is significantly different from the familiar knowledge (core KB), then key decisions have to be made on how the problem-solution should be adapted to the situation, and whether it should assign more weight to the site-specific or the core knowledge.

This means that one should be careful not to "put the horse before the cart," so to speak: just as species respond to the environment's changing conditions (in order to survive) and not the other way around, an operational adaptation apparatus, such as a probability conditional, should account for the relative importance of the varying knowledge sources about aspects of Nature, and not the other way around. In slightly different words, it does not make much sense to mathematically derive a probability conditional and expect it to work under any environmental conditions, thus implying that the Nature will have to continuously adapt itself in order to satisfy the specific mathematical apparatus the humans happen to find convenient. As we shall see later, there exist several proposals concerning the meaning of the term "conditional" in a stochastic reasoning milieu. I suggest that we consider this plurality of options as a sign of health as far as the theory of probability conditionals is concerned.

6.2.2 *Conditionals in a Stochastic Reasoning Milieu*

Against the wishes of the "thieves of Baghdad" (Section 1.3.3), let us start with some history. In his 1651 book *Leviathan*, Thomas Hobbes maintained that, "As for the knowledge of fact, it is originally sense, and ever after memory. And for knowledge of consequence, which I have said before is called science, it is not absolute, but conditional." Otherwise said, scientific knowledge and prediction are conditional. Hobbes' empiricism points out some conceptual aspects of probability conditionals that deserve our attention. In light of the discussion in the preceding sections, stochastic reasoning considers conditionals in a way that allows for physical content- and context-dependent analysis rather than in a purely formal manner. This implies, *inter alia*, that the conditionals should maintain logical and physical consistency among the attributes involved.

6.2.2.1 The Standard Conditional

The *standard conditional* (*SC*) probability of a realization $\chi_{\boldsymbol{p}_j}$ of the S/TRF $X_{\boldsymbol{p}}$, assuming that $\chi_{\boldsymbol{p}_i}$ occurred, is defined by the ratio formula

$$P^{sc}_{KB'}[\chi_{\boldsymbol{p}_j}] = P_{KB}[\chi_{\boldsymbol{p}_j}|\chi_{\boldsymbol{p}_i}] = P_{KB}[\chi_{\boldsymbol{p}_i} \wedge \chi_{\boldsymbol{p}_j}]P^{-1}_{KB}[\chi_{\boldsymbol{p}_i}], \tag{6.5}$$

where $P_{KB}[\chi_{\boldsymbol{p}_i}] \neq 0$, $P^{sc}_{KB'}[\chi_{\boldsymbol{p}_i}] = 1$, and the updated knowledge base, KB$'$, combines the previous KB with the new evidence about $\chi_{\boldsymbol{p}_i}$ (e.g., KB $= G$ and KB$' = K = G \cup S$, where S is the specificatory evidence). This notation duly emphasizes that the probability assessment depends on the agent's epistemic situation in relation to the problem. The $P_{KB}[\chi_{\boldsymbol{p}_i}]$ is termed the *prior* (unconditional) probability, whereas the $P_{KB}[\chi_{\boldsymbol{p}_j}|\chi_{\boldsymbol{p}_i}]$ is called the *posterior* (conditional) probability. The SC probability (6.5) implies that there is an evolution of probability underway in the agent's mind, during which what was the prior model becomes the posterior model. Just as natural evolution, *probability evolution* involves the notion of adaptation that takes the probability from its prior to its posterior stage of development.

It is illustrative to discuss a few examples. Rather trivially, $P_{KB}[\text{KB}] = 1$, regardless of whether KB represents certain or uncertain knowledge. Next, assume that originally one's epistemic situation includes the core knowledge, KB $= G$, in which case the prior probability model can be simply written as $P_G[\chi_{\boldsymbol{p}}]$. Suppose next that the specificatory base S becomes available, in which case the new SC probability model will be $P^{sc}_K[\chi_{\boldsymbol{p}}] = P_G[\chi_{\boldsymbol{p}}|S]$, where the subscript $K = G \cup S$ means that the probability model is constructed on the basis of a total KB that is the union of the G-KB and S-KB. The readers may recall that in Section 3.6.4, we noticed that the union operator in

$G \cup S$ must maintain consistency between the elements of the G-KB and S-KB. In general, $P_G[S]<1$; i.e. in view of G, S is uncertain knowledge and $P_G[\chi_{\boldsymbol{p}}|S] \neq P_G[\chi_{\boldsymbol{p}}]$. In the special case that $P_G[S] = 1, P_G[\chi_{\boldsymbol{p}}|S] = P_G[\chi_{\boldsymbol{p}}]$. That is, if S is derivable from G, the availability of S-KB does not change the agent's probability assessment. The readers may have noticed that the above result reveals one of the paradoxes of the SC probability concept, which is instructive to illustrate with the help of an example. Consider the event *A roulette wheel ball landing double-zero on the j-th spin*, symbolically $\chi_{\boldsymbol{p}_j} = 00$, and let G denote the prior KB. Since the investigator was not present during the event, it is reasonable to try to collect information before calculating the relevant probabilities. In this setting, let $S =$ *An honest and visually acute observer tells the agent that* $\chi_{\boldsymbol{p}_j} = 00$ indeed, so that $P_G[S] = 1$. The latter result implies that $P_G[\chi_{\boldsymbol{p}_j}|S] = P_G[\chi_{\boldsymbol{p}_j}]$. The SC model gives $P_K^{sc}[\chi_{\boldsymbol{p}_j}] = P_G[\chi_{\boldsymbol{p}_j}|S]$, which may not be an appropriate representation of the real-world situation in this case. Indeed, in view of the evidence S, it is reasonable to assume that the posterior $P_G[\chi_{\boldsymbol{p}_j}|S]$ is high, which means that the prior $P_G[\chi_{\boldsymbol{p}_j}]$ is high too. This is an unsatisfactory result, since it is perfectly possible that the unconditional probability $P_G[\chi_{\boldsymbol{p}_j}]$ is very small, even if the conditional probability $P_G[\chi_{\boldsymbol{p}_j}|S]$ is high.

6.2.2.2 Nonstandard Conditionals

Here I will focus on two non-standard probability conditionals, although the readers are reminded that more of them could be considered in Epibraimatics theory. The *material conditional* (*MC*) probability of a realization $\chi_{\boldsymbol{p}_j}$ of a S/TRF $X_{\boldsymbol{p}}$, assuming that $\chi_{\boldsymbol{p}_i}$ occurred, is defined as

$$P_{KB'}^{mc}[\chi_{\boldsymbol{p}_j}] = P_{KB}[\chi_{\boldsymbol{p}_i} \rightarrow \chi_{\boldsymbol{p}_j}] = P_{KB}[\chi_{\boldsymbol{p}_i} \wedge \chi_{\boldsymbol{p}_j}] + P_{KB}[\neg\chi_{\boldsymbol{p}_i}]. \tag{6.6}$$

The MC probability (6.6) is a monotonically increasing function of $\chi_{\boldsymbol{p}_j}$ (fixed $\chi_{\boldsymbol{p}_i}$), and a monotonically decreasing function of $\chi_{\boldsymbol{p}_i}$ (fixed $\chi_{\boldsymbol{p}_j}$). The *equivalent conditional* (*EC*) probability of a realization $\chi_{\boldsymbol{p}_j}$ of the S/TRF $X_{\boldsymbol{p}}$, assuming that $\chi_{\boldsymbol{p}_i}$ occurred, is

$$P_{KB'}^{ec}[\chi_{\boldsymbol{p}_j}] = P_{KB}[\chi_{\boldsymbol{p}_i} \leftrightarrow \chi_{\boldsymbol{p}_j}] = 2\,P_{KB}[\chi_{\boldsymbol{p}_i} \wedge \chi_{\boldsymbol{p}_j}] + P_{KB}[\neg\chi_{\boldsymbol{p}_i}] - P_{KB}[\chi_{\boldsymbol{p}_j}]. \tag{6.7}$$

One may notice that the EC probability (6.7) is a monotonically increasing function of $\chi_{\boldsymbol{p}_j}$ (for $P_{KB}[\chi_{\boldsymbol{p}_i}]>\frac{1}{2}$), and a monotonically decreasing function of $\chi_{\boldsymbol{p}_j}$ ($P_{KB}[\chi_{\boldsymbol{p}_i}]<\frac{1}{2}$). The readers are reminded of the difference between standard logic conditionals and stochastic conditionals considered here. For example, the material conditional of standard logic is truth functional in that the truth value of $\chi_{\boldsymbol{p}_i} \rightarrow \chi_{\boldsymbol{p}_j}$ depends *only* on the truth values of $\chi_{\boldsymbol{p}_i}$ and of $\chi_{\boldsymbol{p}_j}$; the $\chi_{\boldsymbol{p}_i} \rightarrow \chi_{\boldsymbol{p}_j}$ is true if $\chi_{\boldsymbol{p}_i}$ is false, or if $\chi_{\boldsymbol{p}_j}$ is true (e.g., Table 6.2). Thus, in standard logic no connection between $\chi_{\boldsymbol{p}_i}$ *and* $\chi_{\boldsymbol{p}_j}$ is needed. On the other hand, the stochastic conditional of Eq. (6.6) allows for such a connection (as established by the underlying physical law etc.).

6.2.2.3 Relationships Between Conditionals

Section 1.2.3.4 introduced the symbol $\cdot \backslash \cdot$ to denote a conditional in the *broad sense*. For ease of future reference, let us summarize the notation for the SC, MC, and EC probabilities. In the case of the conditional probabilities considered here, $\cdot \backslash \cdot$ becomes $\cdot | \cdot$ (SC), $\cdot \to \cdot$ (MC), and $\cdot \leftrightarrow \cdot$ (EC). Then, one can write:

$$P_{KB}[\chi_{\boldsymbol{p}_j} \backslash \chi_{\boldsymbol{p}_i}] = \begin{cases} P_{KB}[\chi_{\boldsymbol{p}_j} | \chi_{\boldsymbol{p}_i}] = P^{sc}_{KB'}[\chi_{\boldsymbol{p}_j}] \\ P_{KB}[\chi_{\boldsymbol{p}_i} \to \chi_{\boldsymbol{p}_j}] = P^{mc}_{KB'}[\chi_{\boldsymbol{p}_j}], \\ P_{KB}[\chi_{\boldsymbol{p}_i} \leftrightarrow \chi_{\boldsymbol{p}_j}] = P^{ec}_{KB'}[\chi_{\boldsymbol{p}_j}] \end{cases} \tag{6.8}$$

where KB′ denotes that an updated knowledge is associated with a new probability law. On the basis of the above analysis, the three conditional probabilities are related by

$$\begin{aligned} P^{mc}_{KB'}[\chi_{\boldsymbol{p}_j}] &= P^{sc}_{KB'}[\chi_{\boldsymbol{p}_j}] P_{KB}[\chi_{\boldsymbol{p}_i}] + P_{KB}[\neg\chi_{\boldsymbol{p}_i}] \\ &= P^{ec}_{KB'}[\chi_{\boldsymbol{p}_j}] + P_{KB}[\chi_{\boldsymbol{p}_j}] - P_{KB}[\chi_{\boldsymbol{p}_i} \wedge \chi_{\boldsymbol{p}_j}], \end{aligned} \tag{6.9}$$

which is a relationship with a number of interesting practical applications. Let us gain some insight about the conditionals in (6.8) with the help of a few examples. The first example involves two different attributes $X_{\boldsymbol{p}}$ and $Y_{\boldsymbol{p}}$. Given that $X_{\boldsymbol{p}}$ varies with $\boldsymbol{p}$, $P_{KB}[\chi_{\boldsymbol{p}}]$ is the probability of the realization $\chi_{\boldsymbol{p}}$ across space–time. Similarly, $P_{KB}[\psi_{\boldsymbol{p}}]$ is the probability of the realization $\psi_{\boldsymbol{p}}$ across space–time. Then, $P_{KB}[\psi_{\boldsymbol{p}} \backslash \chi_{\boldsymbol{p}}]$ is the probability of the "constrained" realization $\psi_{\boldsymbol{p}}$. If $P_{KB}[\psi_{\boldsymbol{p}} \backslash \chi_{\boldsymbol{p}}] = P_{KB}[\psi_{\boldsymbol{p}}]$, the "unconstrained" realization $\chi_{\boldsymbol{p}}$ does not affect the realization $\psi_{\boldsymbol{p}}$; whereas if $P_{KB}[\psi_{\boldsymbol{p}} \backslash \chi_{\boldsymbol{p}}] \neq P_{KB}[\psi_{\boldsymbol{p}}]$, the "free" realization $\chi_{\boldsymbol{p}}$ induces changes on the thus "constrained" realization $\psi_{\boldsymbol{p}}$. Next, assume that the attribute $X_{\boldsymbol{p}}$ obeys a physical law of change in space–time, and focus on the probability, *The attribute $X_{\boldsymbol{p}}$ takes the $\chi_{\boldsymbol{p}_j}$-value at $\boldsymbol{p}_j$ if and only if it takes the corresponding $\chi_{\boldsymbol{p}_i}$-value at $\boldsymbol{p}_i$, as specified by the physical law*. In other words, $P^{ec}_{KB'}$ is the probability P_{KB}[*Agent asserts that $\chi_{\boldsymbol{p}_i}$ causally influences $\chi_{\boldsymbol{p}_j}$ and* vice versa *in a physical continuum sense*]. In which case, the truth functional conditions of $\chi_{\boldsymbol{p}_i} \leftrightarrow \chi_{\boldsymbol{p}_j}$ in $P^{ec}_{KB'}$ constitute part of the conditions of the physical connection between attribute values across space–time. The invalidity of the stochastic truth-functional is a logically sufficient condition of the corresponding invalidity of the physical connection.

6.2.2.4 A Geometrical Representation

Figure 6.1 shows an illustrative geometrical comparison of the three conditional probabilities of Eq. (6.8). Let the areas A and B be the geometrical domains of the realizations $\chi_{\boldsymbol{p}_i}$ and $\chi_{\boldsymbol{p}_j}$, respectively, and let V be the total area (A, $B \subset V$). The corresponding conditional probabilities are:

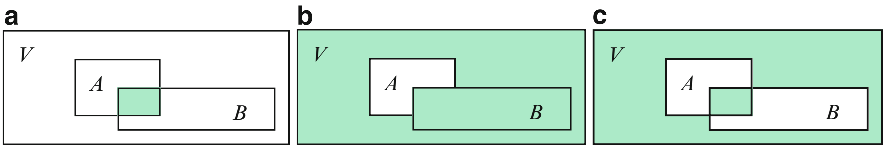

Fig. 6.1 Geometric representations of probability conditionals: (*a*) $P^{sc}_{KB'}$; (*b*) $P^{mc}_{KB'}$; and (*c*) $P^{ec}_{KB'}$

$$\left.\begin{array}{l} P^{sc}_{KB'}[B] = P_{KB}[B|A] = \frac{|A \cap B|}{|A|} \\ P^{mc}_{KB'}[B] = P_{KB}[A \rightarrow\ B] = \frac{|V|-|A|+|A\cap B|}{|V|} \\ P^{ec}_{KB'}[B] = P_{KB}[A \leftrightarrow\ B] = \frac{|V|-|A|-|B|+2|A\cap B|}{|V|} \end{array}\right\} \quad (6.10)$$

The shaded areas in Fig. 6.1 represent the nominators in (6.10). It is visually obvious that $P^{mc}_{KB'}[B] \geqslant P^{ec}_{KB'}[B]$; and after some trivial manipulations of the ratios in (6.10), one finds that $P^{mc}_{KB'}[B] \geqslant P^{sc}_{KB'}[B]$. As we saw in our discussion of Table 6.2, a truth-table is constructed using a combination of formal and intuitive considerations. In a similar vein, for stochastic calculus purposes the entity $B \mid A$ may be defined on the basis of the geometrical representation of the corresponding probabilities (Fig. 6.1). In the case [*A*, *B* are *T*], e.g., $B \mid A$ is formally assigned a value (*T*), since the ratio $\frac{|A\cap B|}{|A|}$ is finite (non-zero). On the other hand, in the case [*A* is *F*, *B* is *T*], the $B \mid A$ can not be assigned a value in the stochastic sense, since the ratio is not defined. The readers may notice that, while one can assign a meaning to the *MC* and *EC* operators directly from *A* and *B*, the meaning of *SC* is assigned indirectly in terms of the corresponding probability function of *A* and *B*.

6.2.3 *Formulas of Stochastic Calculus*

Herein, for simplicity in notation only the subscript *KB* will be used when appropriate, and its actual meaning should be understood from the context. Table 6.6 gives a summary of probability formulas interpreted in a stochastic reasoning milieu. As usual, implicit to any P_{KB} is a metalanguage assertion that is not definite but subjected on the agent's situation (available KBs etc.). In stochastic reasoning terms, the excluded middle law becomes $P_{KB}[\chi_{\boldsymbol{p}} \vee (\neg\chi_{\boldsymbol{p}})] = 1$; and using Axiom 3 (Section 4.4.3) yields Eq. (6.11). This gives a new twist to the standard law. In Eqs. (6.12)–(6.13), (6.16), $\Lambda^m_{i=1}\, \chi_{p_i} = \chi_{p_1} \wedge ... \wedge \chi_{p_m}$ and $V^m_{i=1}\, \chi_{\boldsymbol{p}_i} = \chi_{p_1} \vee ... \vee \chi_{p_m}$. If $\chi_{p_i} \rightarrow\ \neg\chi_{p_j}$ $(1 \leqslant i < j \leqslant m)$ – i.e. any realizations χ_{p_i}, χ_{p_j} are mutually exclusive – then Eq. (6.12) reduces to (6.13). If all possible realizations, say *n*, are considered, i. e. $P_{KB}[V^n_{i=1}\, \chi_{p_i}] = 1$, one gets (6.14) for any χ_{p_i}, χ_{p_j}. Assuming $P_{KB}[\chi_{p_j}] > 0$, Eq. (6.14) yields (6.15). Eq. (6.30) assumes that the bivariate law of the attribute realizations χ_{p_i}, χ_{p_j} are decomposed into its univariate probabilities. No obvious interpretation is always available for such an assumption. An interesting case is Eq. (6.32): when χ_{p_j} is a certain realization, (6.32a) is an expected result; (6.32b) is

Table 6.6 Summary of stochastic reasoning formulas

Excluded middle rule	$P_{KB}[\chi_{\mathbf{p}}] + P_{KB}[\neg\chi_{\mathbf{p}}] = 1$	(6.11)
Disjunction (addition) rule	$P_{KB}[V_{i=1}^{m}\chi_{p_i}] = \sum_{i=1}^{m} P_{KB}[\chi_{p_i}] - \sum_{i\neq j,\ \binom{m}{2}\ pairs}^{m}\sum^{m} P_{KB}[\chi_{p_i} \wedge \chi_{p_j}] + \sum_{i\neq j\neq k,\ i\neq k,\ \binom{m}{3}\ pairs}^{m}\sum^{m}\sum^{m} P_{KB}[\chi_{p_i} \wedge \chi_{p_j} \wedge \chi_{p_k}] - \ldots + P_{KB}[\Lambda_{i=1}^{m}\chi_{p_i}]$	(6.12)
Mutually exclusiveness	$P_{KB}[V_{i=1}^{m}\chi_{p_i}] = \sum_{i=1}^{m} P_{KB}[\chi_{p_i}]$	(6.13)
Composite (total) rule $P_{KB}[V_{i=1}^{n}\chi_{\mathbf{p}_i}] = 1$	$P_{KB}[\chi_{\mathbf{p}_i}] = \sum_{j=1}^{n} P_{KB}[\chi_{\mathbf{p}_i} \wedge \chi_{\mathbf{p}_j}]$	(6.14)
Composite (total) rule $P_{KB}[\chi_{\mathbf{p}_j}] > 0$	$P_{KB}[\chi_{\mathbf{p}_i}] = \sum_{j=1}^{n} P_{KB}[\chi_{\mathbf{p}_i}\|\chi_{\mathbf{p}_j}]P_{KB}[\chi_{\mathbf{p}_j}]$	(6.15)
Conjunction (multiplication) rule	$P_{KB}[\Lambda_{i=1}^{m}\chi_{\mathbf{p}_i}] = P_{KB}[\chi_{\mathbf{p}_1}]P_{KB}[\chi_{\mathbf{p}_2}\|\chi_{\mathbf{p}_1}] P_{KB}[\chi_{\mathbf{p}_3}\|\ \chi_{\mathbf{p}_1} \wedge \chi_{\mathbf{p}_2}]..P_{KB}[\chi_{\mathbf{p}_m}\|\Lambda_{i=1}^{m-1}\chi_{\mathbf{p}_i}]$	(6.16)
Entailment rule $\chi_{\mathbf{p}_i} \therefore \chi_{\mathbf{p}_j}$	$P_{KB}[\chi_{\mathbf{p}_i}] \leq P_{KB}[\chi_{\mathbf{p}_j}]$	(6.17)
Disjunction-Conjunction Inequalities	$P_{KB}[\chi_{\mathbf{p}_i}], P_{KB}[\chi_{\mathbf{p}_j}] \leq P_{KB}[\chi_{\mathbf{p}_i} \vee \chi_{\mathbf{p}_j}]$	(6.18)
	$P_{KB}[\chi_{\mathbf{p}_i} \wedge \chi_{\mathbf{p}_j}] \leq P_{KB}[\chi_{\mathbf{p}_i}], P_{KB}[\chi_{\mathbf{p}_j}]$	(6.19)
	$P_{KB}[\chi_{\mathbf{p}_i}] + P_{KB}[\chi_{\mathbf{p}_j}] - 1 \leq P_{KB}[\chi_{\mathbf{p}_i} \wedge \chi_{\mathbf{p}_j}]$	(6.20)
Conditional Inequalities	$P_{KB}[\chi_{\mathbf{p}_j}\|\chi_{\mathbf{p}_i}] \leq P_{KB}[\chi_{\mathbf{p}_i} \to \chi_{\mathbf{p}_j}]$	(6.21)
	$P_{KB}[\chi_{\mathbf{p}_i} \leftrightarrow \chi_{\mathbf{p}_j}] \leq P_{KB}[\chi_{\mathbf{p}_i} \to \chi_{\mathbf{p}_j}]$	(6.22)
	$P_{KB}[\chi_{\mathbf{p}_j}] \leq P_{KB}[\chi_{\mathbf{p}_i} \to \chi_{\mathbf{p}_j}]$	(6.23)
	$P_{KB}[\chi_{\mathbf{p}_i}]P_{KB}[\chi_{\mathbf{p}_j}\|\chi_{\mathbf{p}_i}] \leq P_{KB}[\chi_{\mathbf{p}_j}]$	(6.24)
	$P_{KB}[\chi_{\mathbf{p}_i} \to \chi_{\mathbf{p}_j}] \geq \begin{cases} P_{KB}[\chi_{\mathbf{p}_j}] \\ P_{KB}[\chi_{\mathbf{p}_i} \wedge \chi_{\mathbf{p}_j}] \end{cases}$	(6.25a, b)
Special cases $P_{KB}[\chi_{\mathbf{p}_i}] = 1$	$\begin{cases} P_{KB}[\chi_{\mathbf{p}_j}\|\chi_{\mathbf{p}_i}] = P_{KB}[\chi_{\mathbf{p}_i} \to \chi_{\mathbf{p}_j}] = P_{KB}[\chi_{\mathbf{p}_i} \leftrightarrow \chi_{\mathbf{p}_j}] \\ = P_{KB}[\chi_{\mathbf{p}_j}] \end{cases}$	(6.26)
$P_{KB}[\chi_{\mathbf{p}_j}\|\chi_{\mathbf{p}_i}] = 1$	$\begin{cases} P_{KB}[\chi_{\mathbf{p}_i} \to \chi_{\mathbf{p}_j}] = 1 \\ P_{KB}[\chi_{\mathbf{p}_i} \leftrightarrow \chi_{\mathbf{p}_j}] = 1 + P_{KB}[\chi_{\mathbf{p}_i}] - P_{KB}[\chi_{\mathbf{p}_j}] \end{cases}$	(6.27a, b)
$P_{KB}[\chi_{\mathbf{p}_i} \to \chi_{\mathbf{p}_j}] = 1$	$\begin{cases} P_{KB}[\chi_{\mathbf{p}_i}] = P_{KB}[\chi_{\mathbf{p}_j}] \\ P_{KB}[\chi_{\mathbf{p}_j}\|\chi_{\mathbf{p}_i}] = 1 \end{cases}$	(6.28)

(continued)

Table 6.6 (continued)

$P_{KB}[\chi_{p_i} \leftrightarrow \chi_{p_j}] = 1$	$P_{KB}[\chi_{p_i}] = P_{KB}[\chi_{p_j}]$	(6.29)
$\left. \begin{array}{l} P_{KB}[\chi_{p_j}\vert\chi_{p_i}] = [P_{KB}(\chi_{p_j}) - P_{KB}(\neg\chi_{p_i})] \\ \quad [P_{KB}(\chi_{p_i}) - P_{KB}(\neg\chi_{p_i})]^{-1} \end{array} \right\}$	$P_{KB}[\chi_{p_j}\vert\chi_{p_i}] = P_{KB}[\chi_{p_i} \to \chi_{p_j}]$	(6.30)
$\left. \begin{array}{l} P_{KB}[\chi_{p_j}\vert\chi_{p_i}] = 1 \wedge \\ P_{KB}[\chi_{p_j}\vert\neg\chi_{p_i}] = 0 \end{array} \right\}$	$P_{KB}[\chi_{p_i} \to \chi_{p_j}] = 1$	(6.31)
$P_{KB}[\chi_{p_j}] = 1$	$\left\{ \begin{array}{l} P_{KB}[\chi_{p_j}\vert\chi_{p_i}] = P_{KB}[\chi_{p_i} \to \chi_{p_j}] = 1 \\ P_{KB}[\chi_{p_j} \leftrightarrow \chi_{p_i}] = P_{KB}[\chi_{p_i}] \end{array} \right.$	(6.32a, b)
$P_{KB}[\chi_{p_j}\vert\neg\chi_{p_i}] = 0$	$\left\{ \begin{array}{l} P_{KB}[\chi_{p_j}\vert\chi_{p_i}] = P_{KB}[\chi_{p_i}]\,P_{KB}^{-1}[\chi_{p_i}] \\ P_{KB}[\chi_{p_j} \to \chi_{p_i}] = P_{KB}[\chi_{p_j} \leftrightarrow \chi_{p_i}] \\ \quad = 1 - P_{KB}[\chi_{p_i}] + P_{KB}[\chi_{p_j}] \end{array} \right.$	(6.33a, b)

not obvious at first sight, but becomes so if one notices that $P_{KB}[\chi_{p_j} \leftrightarrow \chi_{p_i}] = P_{KB}[\chi_{p_i} \to \chi_{p_j}] + P_{KB}[\chi_{p_j} \to \chi_{p_i}] - 1$.[17]

The P_{KB}^{mc} and P_{KB}^{ec} conditionals have some interesting mathematical features that can help us avoid some difficulties of the P_{KB}^{sc} conditional. For example, the SC probability $P_{KB}[\neg(\chi_{p_j}|\chi_{p_i})]$ is formally meaningless, whereas the MC and EC probabilities $P_{KB}[\neg(\chi_{p_i} \to \chi_{p_j})]$ and $P_{KB}[\neg(\chi_{p_i} \leftrightarrow \chi_{p_j})]$, respectively, are both well defined in stochastic logic terms. The readers may notice that unlike SC probability, one can define the associated SC uncertainty $U_{KB}[\neg(\chi_{p_j}|\chi_{p_i})] = 1 - P_{KB}[\chi_{p_j}|\chi_{p_i}]$. This is one of the reasons that the uncertainty formulas are often used instead of the probability formulas in broad sense stochastic reasoning. While P_{KB}^{sc} is not defined in the limiting case $P_{KB}[\chi_{p_i}] = 0$, both P_{KB}^{mc} and P_{KB}^{ec} exist. Then, $P_{KB}^{ec}[\chi_{p_j}] = P_{KB}[\neg\chi_{p_j}]$, which is explained by the fact that, by definition, P_{KB}^{ec} includes the scenarios "$\chi_{p_i} \wedge \chi_{p_j}$" and "$(\neg\chi_{p_i}) \wedge (\neg\chi_{p_j})$." Similarly, if $P_{KB}[\chi_{p_j}] = 0$, $P_{KB}^{sc}[\chi_{p_j}] = P_{KB}[\chi_{p_j}|\chi_{p_i}] = 0$ for any χ_{p_i}. This result implies that an attribute realization χ_{p_j} that is originally considered impossible will remain so, regardless of the support that a related realization χ_{p_i} may offer to it at a later stage of the analysis. The P_{KB}^{ec} avoids this problem since in this case $P_{KB}^{ec}[\chi_{p_j}] = P_{KB}[\neg\chi_{p_i}]$, which is expected given that $P_{KB}[\neg\chi_{p_j}] = 1$. Similar is the behavior of P_{KB}^{mc} (Christakos 2002b).

Let us now turn our attention to inference matters, such as logic modes of considerable value to natural sciences (Hesse, 1975; Bennett and Hacker, 2003). In Section 6.1.4, we briefly examined the case in which the attributes X_p and Y_p and their realizations were related by the physical law $\psi_{p_j} = \phi(\chi_{p_i})$. It was shown that the

[17] If $P_{KB}[\chi_{p_j}] = 1$, then $P_{KB}[\chi_{p_i} \to \chi_{p_j}] = 1$, and $P_{KB}[\chi_{p_j} \to \chi_{p_i}] = P_{KB}[\chi_{p_i}]$, which yields Eq. (6.32b).

Table 6.7 S/TRF inferences

$\left.\dfrac{\psi_{p_j}\vert\chi_{p_i}}{\therefore \chi_{p_i} \rightarrow \psi_{p_j}}\right\}$, then $U_{KB}[\chi_{p_i} \rightarrow \psi_{p_j}] \leq U_{KB}[\psi_{p_j}\vert\chi_{p_i}]$	$\left.\dfrac{\chi_{p_i}, \psi_{p_j}}{\therefore \psi_{p_j}\vert\chi_{p_i}}\right\}$, then $U_{KB}[\psi_{p_j}\vert\chi_{p_i}] \leq U_{KB}[\chi_{p_i}] + U_{KB}[\psi_{p_j}]$
$\left.\begin{array}{l}\neg\chi_{p_i}\vert(\chi_{p_i} \vee \psi_{p_j}) \\ \neg\psi_{p_j}\vert\neg\chi_{p_i} \\ \hline \therefore\psi_{p_j}\vert(\chi_{p_i} \vee \psi_{p_j})\end{array}\right\}$, then $U_{KB}[\psi_{p_j}\vert(\chi_{p_i} \vee \psi_{p_j})] \leq U_{KB}[\neg\chi_{p_i}\vert(\chi_{p_i} \vee \psi_{p_j})] + U_{KB}[\neg\psi_{p_j}\vert\neg\chi_{p_i}]$	$\left.\begin{array}{c}\chi_{p_i} \\ \psi_{p_j}\vert\chi_{p_i} \\ \hline \therefore \psi_{p_j}\end{array}\right\}$, then $U_{KB}[\psi_{p_j}] \leq U_{KB}[\chi_{p_i}] + U_{KB}[\psi_{p_j}\vert\chi_{p_i}]$
$\left.\begin{array}{c}\psi_{p_j}\vert\chi_{p_i} \\ \zeta_{p_k}\vert(\chi_{p_i} \wedge \psi_{p_j}) \\ \hline \therefore \zeta_{p_k}\vert\chi_{p_i}\end{array}\right\}$, then $U_{KB}[\zeta_{p_k}\vert\chi_{p_i}] \leq U_{KB}[\psi_{p_j}\vert\chi_{p_i}] + U_{KB}[\zeta_{p_k}\vert(\chi_{p_i} \wedge \psi_{p_j})]$	

inference that the physical law $\psi_{p_j} = \phi(\chi_{p_i})$ entails the material implication $\chi_{p_i} \rightarrow \psi_{p_j}$ is valid in a certain stochastic sense. Now, let us consider the inference: If $[\psi_{p_j} = \phi(\chi_{p_i})] \therefore [\psi_{p_j}|\chi_{p_i}]$,[18] then $U_{KB}[\psi_{p_j}|\chi_{p_i}] \leq \ U_{KB}[\psi_{p_j} = \phi(\chi_{p_i})]$. The last inequality is not always true. Hence, the inference that the physical law entails the SC probability is not surely valid in the above stochastic sense. Table 6.7 displays examples of useful stochastic calculus rules in a space–time domain. In view of the above and similar considerations, for stochastic calculus to be of practical use in the IPS framework, the in situ problem should be conceived and presented in an adequate manner; formal definitions and rules should be physically meaningful in the problem setting; and numerical values should be assigned to basic probabilities, from which new ones are derived using the rules. Surely, it will require significant commitment and energy from the IPS participants to develop the innovative reasoning process often required by an interdisciplinary study and achieve radical outcomes. The will to succeed must be there and the courage to step out of comfort zones.

6.3 The Role of Specificatory Evidence in Probability

As before, let G and S denote, respectively, the core KB (available at the structural or prior stage of the analysis) and the site-specific KB (emerging at a meta-prior stage) concerning an attribute X_p with possible realizations χ_p that vary across space–time. Depending on the form of the conditional probability assumed (Section 6.2.2), a useful set of rules for adapting the G-based probability model in light of the S-KB are

[18] As before (Section 6.2.2.4), the stochastic logic operator $\psi_{p_j}|\chi_{p_i}$ may be assigned the geometric meaning of Fig. 6.1. The focus of the present analysis is the associated uncertainty and probability functions.

readily available. The rules show that when there is uncertainty about an attribute realization $\chi_{\boldsymbol{p}}$, the observational evidence (S) could raise or lower this uncertainty.

6.3.1 Reverend Bayes and His Critics

In cases in which the SC probability definition is considered adequate (Section 6.2.2.1), the following rule, also known as *Bayes* theorem, is formally valid:

$$P_G[\chi_{\boldsymbol{p}}|S] = P_G[S|\chi_{\boldsymbol{p}}]\, P_G[\chi_{\boldsymbol{p}}]\, P_G^{-1}[S] \tag{6.34}$$

with $P_G[S] \neq 0$. According to the celebrated Bayes formula, the SC probability of an attribute realization $\chi_{\boldsymbol{p}}$ given S is equal to the conditional probability of S given $\chi_{\boldsymbol{p}}$, times the ratio of the prior probabilities of $\chi_{\boldsymbol{p}}$ and S. The epistemology underlying Bayes rule (6.34) is that the posterior K-based probability of $\chi_{\boldsymbol{p}}$ is equal to the prior probability of $\chi_{\boldsymbol{p}}$ subject to S, i.e. $P_K[\chi_{\boldsymbol{p}}] = P_G[\chi_{\boldsymbol{p}}|S]$, $K = G \cup S$. Obviously, $P_K[S] = 1$, i.e. after a dataset S has been obtained, its probability of occurrence is 1.

There are several ways to compare Bayesian rule (6.34) with the non-standard rules of stochastic logic. In light of the MC probability (Section 6.2.2.2), e.g., the following rule is formally valid:

$$P_G[S \rightarrow \ \chi_{\boldsymbol{p}}] = P_G[\chi_{\boldsymbol{p}} \rightarrow \ S] + P_G[\chi_{\boldsymbol{p}}] - P_G[S]; \tag{6.35}$$

i.e., the MC probability of S implying $\chi_{\boldsymbol{p}}$ is equal to the MC probability of $\chi_{\boldsymbol{p}}$ implying S, plus the difference of the prior probabilities of $\chi_{\boldsymbol{p}}$ and S. One interesting difference between (6.34) and (6.35) is that unlike the Bayes rule (6.34), the MC rule (6.35) is not prone to the problems of the priors: assigning a zero prior probability $P_G[\chi_{\boldsymbol{p}}]$, e.g., does not force the posterior MC probability $P_G[S \rightarrow \ \chi_{\boldsymbol{p}}]$ to be zero; and unlike Eq. (6.34), the Eq. (6.35) exists when $P_G[S] = 0$. The readers may also observe that, while the Bayes rule is nonadditive, the MC rule is additive. On the other hand, the readers may find it interesting that Eq. (6.34) can be also written as

$$\log P_G[\chi_{\boldsymbol{p}}|S] = \log P_G[S|\chi_{\boldsymbol{p}}] + \log P_G[\chi_{\boldsymbol{p}}] - \log P_G[S], \tag{6.36}$$

i.e., in terms of logarithms the Bayesian rule (6.34) has the same additive form as rule (6.35).

Bayes Eq. (6.34) leads to certain interesting results. Assume, e.g., that learning about the physical attribute value $\chi_{\boldsymbol{p}_i}$ at $\boldsymbol{p}_i$ increases the probability of the attribute value $\chi_{\boldsymbol{p}_j}$ at $\boldsymbol{p}_j$, i.e. $P_G[\chi_{\boldsymbol{p}_j}|\chi_{\boldsymbol{p}_i}] > P_G[\chi_{\boldsymbol{p}_j}]$; then, Eq. (6.34) implies that $P_G[\chi_{\boldsymbol{p}_i}|\chi_{\boldsymbol{p}_j}] > P_G[\chi_{\boldsymbol{p}_i}]$ (i.e. learning about the attribute value $\chi_{\boldsymbol{p}_j}$ increases the probability of the value $\chi_{\boldsymbol{p}_i}$), which makes sense given that $\chi_{\boldsymbol{p}_i}$ and $\chi_{\boldsymbol{p}_j}$ are linked (via a physical law, an empirical relationship etc.). In the discrete case, the value of $P_K[\chi_{\boldsymbol{p}_i}] = P_G[\chi_{\boldsymbol{p}_i}|S]$ in Eq. (6.34) can be derived without using $P_G[S]$ in terms of the expression $P_K[\chi_{\boldsymbol{p}_i}] = \{\sum_{i=1}^{n} P_G[S|\chi_{\boldsymbol{p}_i}]\, P_G[\chi_{\boldsymbol{p}_i}]\}^{-1} P_G[S|\chi_{\boldsymbol{p}_j}]\, P_G[\chi_{\boldsymbol{p}_j}]$. On the other hand, Bayes rule (6.34) can lead to results that are not always physically meaningful (see Section 6.3.1.2). The take home lesson is that the Bayes rule is a valuable tool, which, though, must be used in the right context (physical, logical etc.).

6.3.1.1 Interpretive Matters

The formal validity of Bayes rule (6.34) is rather indisputable. However, when it comes to in situ applications, the issue is not mathematics but the interpretation of Bayes rule.[19] Commonly made assumptions include: (*a*) probabilities are interpreted in a nonfrequentist sense; (*b*) prior probabilities can be always defined; and (*c*) the conditional $P_G[\chi_p|S]$ is defined in the standard sense of Eq. (6.5). In the case of Assumption *a*, the subjective probability interpretation (Section 4.4.4.3) is often used. Assumption *b* implies that the probability can be defined in a degree-of-belief sense, as a measure of the completeness of the available knowledge (in some cases the principle of indifference is employed), or by asking the investigators to make bets. Whatever the case may be, it is crucial that special attention is given to what kind of substantive support one can provide for the specific choice of priors. Concerning Assumption *c*, the SC probability $P_G[\chi_p|S]$ of Eq. (6.34) is defined in terms of a ratio. The probability of χ_p given S is the ratio of the joint probability of χ_p and S over the probability of S. According to a relevant criterion, the S confirms, disconfirms, or is irrelevant to χ_p, depending on whether $P_G[\chi_p|S]$ is greater, smaller, or equal to $P_G[\chi_p]$, respectively (Schlesinger 1991; Howson and Urbach 1993).

The readers will probably agree that nothing is sacred when it comes to matters of human inquiry, which implies that a meaningful association of the Assumptions *a*-*c* with the in situ situation must be first and foremost established. Then, adequate interpretations can be drawn from the integration of this association and Bayesian analysis in an IPS context. While there is no doubt that the implementation of the Bayesian approach can provide brilliant solutions to many real-world problems, by no means it should be considered a panacea.

6.3.1.2 Criticisms of Bayesianism

In a real sense, critics seem to have issues with almost all matters pertaining to Bayesianism, thus arguing rather strongly that in several important cases Bayesianism, considered as an epistemology, is an inadequate approach. A brief summary of some of the criticisms of Bayesianism is as follows.

Substance: Some people argue that often it does not make sense to talk about the prior probability $P_G[\chi_p]$ in Eq. (6.34), since it may be physically impossible to define the probability of an attribute value being true prior to any observation.

[19] This also demonstrates the importance of an observation already made in a previous section: the most serious difficulties of probability are not mathematical but interpretational.

In some other situations, they add, the principle of indifference is not meaningful. On the other hand, one may argue that if prior probabilities are considered within a strong theoretical framework, they could be viewed as "theoretical entities" to be judged by how well they enable the theory to generate posterior probabilities that are meaningful in a scientific context. This is the line of reasoning, e.g., in atomic physics: an initial mass value is assigned to the unobservable electron and then judged on the basis of observable results it leads to.

Exclusivity: There is no reason that the probability should be interpreted exclusively in a subjective way, as many Bayesians insist. A criticism of subjective Bayesianism is that it allows the case in which an entity A is epistemically probable given another entity B, relative to one agent, but possibly not epistemically probable given B, relative to another agent. One can find a variety of in situ cases where the epistemic interpretation, e.g., is more appropriate (Section 4.4.4.2).

S-uncertainty: Bayesianism assumes that since $K = G \cup S$, $P_K[S] = 1$ after the event; i.e., the dataset S is certain knowledge after it is acquired. One could argue, however, that this is often not true in the real-world, since S includes measurements that have considerable uncertainty. Also, Eq. (6.34) is not defined when $P_G[S] = 0$ which, nevertheless, may be a valid probability for S under certain conditions in practice.

Confirmation: Bayesianism seems to confuse real confirmation with mere probability raising, when it claims that any S that raises the probability $P_G[\chi_{\boldsymbol{p}}|S]$, confirms $\chi_{\boldsymbol{p}}$. If, e.g., $P_G[\chi_{\boldsymbol{p}}] = 10^{-6}$ and $P_G[\chi_{\boldsymbol{p}}|S] = 10^{-5} > 10^{-6}$, it is implied that S confirms $\chi_{\boldsymbol{p}}$, which makes little sense since $P_G[\chi_{\boldsymbol{p}}|S]$ is still very small.[20]

Overreliance: For a variety of reasons (scientific, sociological, and cultural), all revolutionary theories are considered highly unlikely or impossible a priori. Einstein's relativity theory, e.g., predicted that $\chi_{\boldsymbol{p}} =$ *Light is bent by the gravitational pull of Sun*. In light of core knowledge, including the prevailing interpretation of evidence at the time, the established view was that light travels in straight lines and, hence, $P_G(\chi_{\boldsymbol{p}}) \approx 0$ a priori. Subsequent eclipse observations obtained by Eddington supported Einstein's theory: if $S =$ *Eddington's eclipse observational data*, then $P_G(S|\chi_{\boldsymbol{p}}) = 1$. But given the ruling worldview of the times, $P_G(S) = \beta <<$ a priori, and $P_G(\chi_{\boldsymbol{p}}|S) = P_G(S|\chi_{\boldsymbol{p}}) P_G(\chi_{\boldsymbol{p}}) P_G^{-1}(S) = 1 \times 0 \times \beta^{-1} = 0$, i.e. Bayes rule gave zero probability to Einstein's prediction. This is due to the apparent overreliance of Bayes rule on a priori assessments. Note that the MC and EC probabilities give $P_G[S \rightarrow \chi_{\boldsymbol{p}}] = P_G[S \leftrightarrow \chi_{\boldsymbol{p}}] = P_G[\neg S] = 1 - \beta$, i.e. they promptly assigned high probability to Einstein's prediction.

Ignorance: According to Eq. (6.34), $P_G[S|\chi_{\boldsymbol{p}}] \propto P_G^{-1}[\chi_{\boldsymbol{p}}]$. But since the probability $P_G[\chi_{\boldsymbol{p}_j}]$ is essentially unknown,[21] from a theory of knowledge perspective this would

[20] Taking this criterion literally, one could claim that the fact that one got into an airplane confirms that one will die, since it raised the probability of one dying in an airplane crash from 0 to about 10^{-7}.

[21] In practice the choice of $P_G[\chi_{\boldsymbol{p}_j}]$ is usually arbitrary; i.e., its shape is chosen from a list of convenient models, Gaussian, Poisson etc.

imply that (6.34) attempts to extract knowledge out of ignorance. This is inappropriate from an epistemological viewpoint, and not only.

Reversibility: Bayes rule is based on the premise that, "If the probability of χ_{p_j} given χ_{p_i} exists, then the probability of χ_{p_i} given χ_{p_j} exists." However, this assumption may be violated in situ on physical grounds. Let us assume, e.g., that $P_G[\chi_{p_j}|\chi_{p_i}]$ measures the probability that a phenomenon will undergo the transition from state χ_{p_i} to state χ_{p_j}, in which case the $P_G[\chi_{p_i}|\chi_{p_j}]$ in Eq. (6.34) refers to the probability of the reverse process "χ_{p_j} to χ_{p_i}," which may happen to be physically impossible (e.g., the evolution and radioactive decay processes are irreversible).

Propensity: The propensity interpretation of probability (Section 4.4.4.1) measures causal tendency, and when causality is asymmetric, the propensity cannot be inverted. Consider, e.g., a medical test that produces false-positive or false-negative results. It makes sense to claim that a sick agent has a propensity to give a positive test result, but not the other way around (it would be nonsensical to claim that a positive test result has a propensity to give a sick agent). Hence, a propensity cannot obey Eq. (6.34). This is another case of irreversibility in the sense noted earlier.

At a different level of debate, one cannot avoid noticing some signs of desperation. According to John Skilling, e.g., there is only one "valid defense of using non-Bayesian methods, namely incompetence" (Skilling 1991: 24). Also, the advertising game (securing attractive brand names for scientific entities, using promotional tricks, etc.) seems to be taken too seriously by certain Bayesians. James O. Berger (2006a: 387), e.g., suggests that "the statistics profession, in general, hurts itself by not using attractive names for its methodologies, and we should start systematically accepting the 'objective Bayes' name before it is co-opted by others," and that no other name "will carry the same weight outside of statistics as 'objective'." Nothing is more unfitting for a scholar resolved on practicing scientific inquiry than to talk the language of marketing. Berger's gestures are based on establishing an arrangement among group members sharing a common agenda and, therefore, on complete conformism. Many statisticians responded that this sort of marketing tricks cannot be part of scientific inquiry. Otherwise said, they did not fall in the trap of treating as a thesis what is in fact a brand name. Frank Lad (2006: 441) observed that, "The marketing department has taken over from the production department. The goal is neither product quality nor service, but sales." Also, Michael Goldstein (2006: 466) noticed that, "If we claimed to offer a money back guarantee if our statistical analyses were in error, then this would be simple and carry a lot of weight in the user community. However, we can easily imagine the reaction from users who tried to claim the money back guarantee, only to be told that there was no actual guarantee of a refund, but that the Bayesian community had simply judged that to say that there would be a refund would carry a lot of weight outside of statistics."

In reality, neither Bayesianism nor its critics are correct in every conceivable real-world situation. A Bayesian assumption may make sense, e.g., in some economics and finance applications (whether that sense is understood as a process of interpretation, explanation, or understanding), but not in some psychological problems. Cosmides and Tooby (1996) argued that the mind implicitly uses Bayes rule to get the correct solution if it is presented with frequency data, but it fails to do so if it is presented with probabilities of single events. In the end, Bayesianism is a valuable tool of scientific inquiry, but like everything else, it has its own limitations, which is for the investigator to discover and act accordingly, depending on the in situ situation.[22] This is probably the right way to look at the debate between Bayesianism and its critics, and also be prepared to face the fact that often people are ready to defend their ideas to death, provided that these ideas are not clear to them. Which prepares us for the following section.

6.3.2 Good's Varieties of Bayesians and De Gaulle's Varieties of Cheese

There is not a unique interpretation of the formal Bayesian approach. Instead, there are several Bayesian schools, and all of them are more or less confident that theirs is the correct interpretation. In this respect, there is an interesting parallel between the state of Bayesianism and the state of French politics, as expressed by none other than Charles De Gaulle. While serving as President of France, Charles De Gaulle famously complained: "How can one govern a country that has 246 varieties of cheese?" The General might have felt a little better if he knew about the much more complex situation in statistics, as described by Irving John Good (1971): "There are 46656 varieties of Bayesians." Commenting on Good's quote, Stephen E. Fienberg (2006: 431) wrote that, "Today there seem to be at least this many varieties of objective Bayesians, with each seeking out his or her own method for arriving at the perfect objective prior and then allowing for other idiosyncrasies. Each method fails in some important way precisely because of the lack of true normative foundations." There is rather little consensus in Bayesian statistics. No unanimity exists as to either its definitions or its goal. The range of opinions varies from viewing Bayesian analysis as a completely coherent scientific methodology to a mere collection of ad hoc data-processing techniques. In face of this, reason retreats behind a windowless wall of idiosyncrasies. It is then not surprising that some Bayesians seem to contradict themselves. As John P.A. Ioannidis (2007: 1133) wrote, "The claim by two leading Bayesian methodologists [Goodman and Greenland 2007] that a Bayesian approach is somewhat circular and questionable contradicts Greenland's own writings: 'One misconception (of many) about Bayesian analyses is that prior distributions introduce assumptions that are more questionable than assumptions made by frequentist methods (Greenland 2006: 765)'."

[22] The debate has its entertaining moments, as well. For example, when an investigator was asked if he is a "Bayesian" or a "non-Bayesian," he responded that he is an "opportunist," meaning that he would use whatever approach works best for the given in situ conditions.

Some of the most important differences in opinion are due to the characterization of Bayesian analysis as "objective" vs. "subjective," and the far-reaching consequences of this distinction on how a prior probability is conceived and constructed. In particular, the terms "objective prior" and "subjective prior" have been used to denote that the prior has been obtained in an objective way and on the basis of subjective beliefs, respectively. These are highly consequential differences that are worth further investigation. The term "objective" is rather controversial, since it may imply associations with high philosophical ideals, like absolute truth, in which case the objective analysis gives the impression of making unrealistic claims. Moreover, the term "objective" may imply negative connotations for the term "subjective" (as incomplete or inferior consideration). This is ironic, since models of the "objective" prior are constructed using formal procedures, but the choice of the prior model among them is a subjective process. Objective Bayesian analysis relies heavily on a melange of technical models concerning the form of the priors (e.g., Jeffrey's, invariance, and reference models), which, according to thinkers like Joseph B. Kadane (2006: 434), often contradict each other. To many other experts, any attempt to connect objective Bayesian analysis with scientific reasoning is destined to be futile, since the latter uses internally consistent models based on substantive knowledge, whereas the former relies on a multiplicity of models based merely on formal considerations that are often contradictory. Anthony O'Hagan (2006: 445) wrote about "The dangerous heresy of so-called 'objective' Bayesian methods," giving one an idea of the ongoing heated debate. In several cases, the term "subjective" seems to allow for nonexpert opinions, emotional assessments, and the like. Also, other experts argue, it does not have a definite mechanism to discriminate between expert opinions and mere "got feelings." In this respect, subjective Bayesian analysis may suffer from problems of knowledge reliability, internal consistency, cognitive illusions and dissonance, and metacognitive experience discussed in Section 3.9.3. Subjectivity in science certainly exists, although often it has to do more with the way a human agent uses scientific knowledge rather than the knowledge itself. A good physicist uses natural laws in a better way than a not so good one. And the opinion of a world expert in epidemiology carries much more weight than that of a mere practitioner.

The analysis above raises a number of legitimate questions. Given the different belief systems and knowledge sources, can the choice of an adequate prior be a purely statistical matter? Would it rather be an impossible task for a statistician to seek a sort of a "grand unified theory" of priors that would work in every scientific field? Let us consider a few examples. If the prior knowledge is based on physical laws in the form of complex partial differential equations, why is a statistician more qualified to derive the associated prior than a theoretical physicist whose entire career has been devoted to the study of such physical laws? Also, the way a biologist and a social scientist conceive the meaning of the term "prior," and subsequently construct a model of it may vary significantly, due to their different backgrounds, quantitative techniques, and ultimate presumptions. In view of the above, one may find more appropriate a distinction between *formal* (instead of objective), *personalistic* (instead of subjective), and *substantive* priors, to denote that the prior has been constructed based on purely formal considerations, personal beliefs, and scientific knowledge,[23] respectively. Since many in situ problems are multidisciplinary, a carefully thought-out and justified combination of all three elements (formal considerations, personal beliefs, and scientific knowledge) may be needed in certain in situ cases.

6.3.3 Extra Bayesian Nulla Salus[24]

Given the considerable disagreements among Bayesians, the situation has led to never-ending debates about how the method can be effectively applied in the real-world. Under the circumstances, it may not be surprising that some schools of thought insist that their version of Bayesianism applies in every problem under the Sun. This "universality" claim often reflects some sort of disciplinary sauvinism: people make unjustified generalizations, assuming that what happens to be valid in their own domain of expertise remains valid in other disciplines or fields of inquiry. Of course, this is usually an invalid extrapolation that leads to questionable implementations of the Bayesian approach.[25]

Ignoring the Terencian wisdom *ne quid nimis*,[26] sometimes Bayesianism reaches a cult status. In Duke's respected statistics program, e.g., Bayesians seem to have departed on an all-explanatory epistemological adventure of their own. *Extra Bayesian nulla salus* has been elevated to a sacred dogma that "excommunicates" any individual who dares challenge the god Bayes worshiped in Duke's campus. This reminds one of Jezebel's reign,[27] who had ordered the execution of all those who refused to worship the pagan god Baal. Because some things never change, many non-believers avoid walking alone in the streets of Samaria and Durham after dark. In concluding this section, one must remember that "all–explanatory" approaches have an irresistible effect on people. A prime characteristic of these approaches is a tendency for exaggeration: "My view of statistics is that it is much broader than simply a philosophy of reasoning" (Berger, 2006b: 464). Statements of this kind are rather advocatory gestures of thought in the Adornonian sense. If taken literary, the above statement would imply that deep philosophical questions that have challenged the greatest minds for millennia could be answered by Bayesian statistics, as seen through Berger's own visionary eyes.

[23] Especially in situations involving well-developed sciences.

[24] Non-Bayesians are not allowed to enter.

[25] The readers may be amused to find out that the approach has been used, e.g., to support the case of aliens visiting planet earth, to prove God's existence, and to reveal secret codes that supposedly exist in holy scripts.

[26] Nothing in excess.

[27] The ninth century BC Phoenician queen of Israel.

6.3.4 Contextual Alternatives: Isocrates' Concern

Already in the fourth century BC, Isocrates was well aware of the key role of context and content in human affairs, which is why he was concerned that the scroll he sent to king Philip of Macedonia will not convey his real message, because the scroll will first reach the king's secretary, who will read it out to Philip in a formal and customary style, "with no persuasiveness, no indication of changes of feeling, as if he were giving a list of items."[28] *Mutatis mutandis*, when it comes to the formulas of stochastic calculus, they should be used only in the appropriate context as determined by the problem at hand. A good example is the in situ interpretation of "conditional probability," which is the subject of the following lines.

6.3.4.1 Substantive Conditionals

Let $\chi_{\boldsymbol{p}_j}$ be a realization of the attribute $X_{\boldsymbol{p}}$, and let S denote case-specific evidence about $X_{\boldsymbol{p}}$. For example, S may be a different realization $\chi_{\boldsymbol{p}_i}$ of the same attribute, a realization $\psi_{\boldsymbol{p}_i}$ of another attribute $Y_{\boldsymbol{p}}$, or any other sort of relevant knowledge. It is useful to make a distinction between the *substantive* conditional (in situ conditional that emerges in a physical, biological, or social setting) that may be written as

$$\begin{aligned} P_{KB}[\chi_{\boldsymbol{p}_j} \backslash S] &= Prob[Agent's\ assertion\ that\ X_{\boldsymbol{p}_j} \\ &= \chi_{\boldsymbol{p}_j}\ assuming\ that\ S\ is\ valid], \end{aligned} \tag{6.37}$$

and its possible mathematical representations

$$P_{KB}[\chi_{\boldsymbol{p}_j} \backslash S] = \begin{cases} P_{KB}[\chi_{\boldsymbol{p}_j} | S] = P^{sc}_{KB'}[\chi_{\boldsymbol{p}_j}] \\ P_{KB}[S \rightarrow \chi_{\boldsymbol{p}_j}] = P^{mc}_{KB'}[\chi_{\boldsymbol{p}_j}] \\ P_{KB}[S \leftrightarrow \chi_{\boldsymbol{p}_j}] = P^{ec}_{KB'}[\chi_{\boldsymbol{p}_j}] \\ \qquad \ldots \end{cases}, \tag{6.38}$$

where, as usual, KB and KB$'$ are the associated KBs (Section 6.2.2). The readers could make the connection between Eq. (6.38) and Eq. (6.8) of the previous section. The symbol "…" means that, in addition to the conditionals shown in Eq. (6.38), others may also exist and wait to be discovered. Probability is not a purely intuitive

[28] Isocrates' writings often describe situations that are so close to modern times that people assume that the author is a living person. Boman (1970: 148) describes an incident in the 1940s during which a university professor in Oslo read to a group of philology students a passage from Isocrates' political writings, and among those that the students identified as the author were Roosevelt and Churchill.

science (Section 5.2.2.1), in which case one should be ready to rethink what one has intuitively accepted before. Assigning an appropriate mathematical conditional probability to the interpretive conditional probability $P_{KB}[\chi_{\boldsymbol{p}_j} \backslash S]$ can be a complicated matter that depends on the in situ meaning an investigator decides to assign to the symbol "$\cdot \backslash \cdot$".

It is important to understand what is the actual connection between the attribute and the agent's state of knowledge about it. In this respect, some noteworthy issues emerge that can be summarized as follows: (*a*) In the case of $P_{KB}[\chi_{\boldsymbol{p}_j} \backslash \psi_{\boldsymbol{p}_i}]$, do the realizations $\chi_{\boldsymbol{p}_j}$ and $\psi_{\boldsymbol{p}_i}$ belong to the same mechanism (physical, biological, social, etc.) or are linked to different ones? Is the connection between $\chi_{\boldsymbol{p}_j}$ and $\psi_{\boldsymbol{p}_i}$ substantive or ad hoc and artificial? (*b*) In the case of $P_{KB}[\chi_{\boldsymbol{p}_j} \backslash \chi_{\boldsymbol{p}_i}]$, are $\chi_{\boldsymbol{p}_i}$ and $\chi_{\boldsymbol{p}_j}$ connected by a causal relationship (law of change)? Or is the relationship merely correlational? Or is it rather unstructured? (*c*) What weights should the conditional probability assign to different knowledge sources? As usual, let us consider a few simple examples. In the first example, assume that $P_{KB}[\chi_{\boldsymbol{p}_j} \backslash \neg\psi_{\boldsymbol{p}_i}] = 0$. If the $P_{KB'}^{sc}$ is used, it may imply, on physical grounds, that the $\chi_{\boldsymbol{p}_j}$ and $\psi_{\boldsymbol{p}_i}$ refer to different situations (Item *a*). If the $P_{KB'}^{mc}$ is assumed, then the falsity of $\psi_{\boldsymbol{p}_i}$ would support the validity of $\psi_{\boldsymbol{p}_i} \to \chi_{\boldsymbol{p}_j}$, in which case a causal law may exist (Item *b*). Let us now focus on Item *c*. Assume that initially the KB $\equiv G$ implies $P_G[\chi_{\boldsymbol{p}_i} \in (4.7, 5.2)] = 0.19$. Subsequently, in view of S it is found that $P_S[\chi_{\boldsymbol{p}_i} \in (4.7, 5.2)] = 0.35$. What model should one use for $P_G[\chi_{\boldsymbol{p}_j} \backslash \chi_{\boldsymbol{p}_i}]$? Will the P_K^{sc}, the P_K^{mc}, or the P_K^{ec} model be the most appropriate choice? The best choice will depend (*inter alia*) on the agent's substantive decision to assign more weight to $P_G[\chi_{\boldsymbol{p}_i}]$ or to $P_S[\chi_{\boldsymbol{p}_i}]$; i.e., whether the agent's epistemic situation[29] favors S-KB or puts more trust in G-KB, given that it includes a fundamental physical law (Section 7.3.4). In this respect, Item *c* may be also related to the metacognitive experience phenomenon (Section 3.9.3), i.e. the ease or difficulty with which data is brought to the agent's mind and the fluency with which new data can be processed. The conditional dependence indicator introduced next can be also helpful in the agent's effort to make a meaningful choice between the P_K^{sc}, P_K^{mc}, and P_K^{ec} models.

6.3.5 Conditional Dependence Indicator

A useful assessment of the dependence of a realization $\chi_{\boldsymbol{p}_j}$ on S is given by the space–time *conditional dependence indicator* (CDI),

$$\Phi_S = P_{KB}[\chi_{\boldsymbol{p}_j} \backslash S] - P_{KB}[\chi_{\boldsymbol{p}_j}]. \tag{6.39}$$

[29] I.e. professional background, ultimate presumptions, scientific knowledge, and beliefs.

Table 6.8 Conditional dependence indicators

Statistical conditional	$\Phi_S^{sc} = P_{KB}[\chi_{p_j}\vert S] - P_{KB}[\chi_{p_j}]$ $= P_{KB}^{-1}[S]\{P_{KB}[S \wedge \chi_{p_j}] - P_{KB}[S]P_{KB}[\chi_{p_j}]\}$ $= P_{KB}[\neg S]\{P_{KB}[\chi_{p_j}\vert S] - P_{KB}[\chi_{p_j}\vert\neg S]\}$	(6.40a–c)
Material conditional	$\left.\begin{aligned}\Phi_S^{mc} &= P_{KB}[S \rightarrow \chi_{p_j}] - P_{KB}[\chi_{p_j}] \\ &= 1 - P_{KB}[S \vee \chi_{p_j}] \geq 0\end{aligned}\right\}$	(6.41a–b)
Equivalent conditional	$\Phi_S^{ec} = P_{KB}[S \leftrightarrow \chi_{p_j}] - P_{KB}[\chi_{p_j}]$	(6.42)
Relationships	$\Phi_S^{mc} = \Phi_S^{ec} + P_{KB}[\chi_{p_j}] - P_{KB}[S \wedge \chi_{p_j}]$	(6.43)
	$\Phi_S^{mc} = \Phi_S^{ec} - \Phi_S^{sc} P_{KB}[S] + P_{KB}[\chi_{p_j}]P_{KB}[\neg S]$	(6.44)
	$\Phi_S^{mc} \geq \Phi_S^{ec}$	(6.45)
	$\Phi_S^{mc} \geq \Phi_S^{sc}$	(6.46)
	$\Phi_S^{sc}\begin{cases}\geq 0 \textit{ if } X_{\boldsymbol{p}} \textit{ and } S \textit{ are positively dependent} \\ \leq 0 \textit{ if } X_{\boldsymbol{p}} \textit{ and } S \textit{ are negatively dependent}\end{cases}$	(6.47)
Examples		
$P_{KB}[S] = 1$	$\Phi_S^{sc} = \Phi_S^{mc} = \Phi_S^{ec} = 0$	(6.48)
$P_{KB}[\chi_{\mathbf{p}_j}] = 1$	$\Phi_S^{sc} = \Phi_S^{mc} = 0,\ \Phi_S^{ec} = P_{KB}[S] - 1$	(6.49)
$P_{KB}[\chi_{\mathbf{p}_j}\vert S] = 1$	$\Phi_S^{sc} = \Phi_S^{mc} = 1 - P_{KB}[\chi_{p_j}],\ \Phi_S^{ec} = 1 - 2P_{KB}[\chi_{p_j}] - P_{KB}[S]$	(6.50)
$P_{KB}[\chi_{p_j}\vert\neg S] = 0$	$\Phi_S^{sc} = P_{KB}^{-1}[S]\,P_{KB}[\neg S]\,P_{KB}[\chi_{p_j}],\ \Phi_S^{mc} = \Phi_S^{ec} = 1 - P_{KB}[S]$	(6.51)

Contingent on the agent's outlook, Φ_S measures the contribution of S on the occurrence of χ_{p_j}, or the predictability of χ_{p_j} from S. Assuming different probability conditionals – SC, MC, and EC – Eq. (6.39) leads to some interesting results shown in Table 6.8.

In practice, one can use (6.39) for different types of conditionals, and calculate which one leads to the highest Φ_S value for the specified in situ situation. Some illustrative examples are given in Eqs. (6.48)–(6.51) of Table 6.8. One may notice that for the same attribute $X_{\boldsymbol{p}}$, the different CDIs (Φ_S^{sc},Φ_S^{mc}, and Φ_S^{ec}) offer different dependence assessments between S and χ_{p_j}.

6.3.6 *William James' Sea of Possibilities*

Let us take stock. From a stochastic reasoning point of view, mental functions are associated with an evolutionary process in the study of an attribute $X_{\boldsymbol{p}}$ that involves three notions: Potentiality, probability, and actuality. Potentiality and actuality are basic ingredients of reality. In between them, stochastic reasoning inserts the notion of probability that offers a link between the potential and the actual. Relevant is the quote by William James: "Actualities seem to float in a wider sea of possibilities from out of which they were chosen; and somewhere, indeterminism says, such possibilities exist, and form part of the truth." As noted earlier, this evolutionary process includes three main stages: At the *prior* stage of the study, the agent's mental function assigns attribute realizations $\chi_{\boldsymbol{p}}^{(1)}, \ldots, \chi_{\boldsymbol{p}}^{(R)}$ across space–time $\boldsymbol{p}$

(this is the V_G set of all logically and physically possible realizations given G-KB). The V_G is often known prior to actualization (e.g., in physical situations, the values of an attribute $X_{\boldsymbol{p}}$ are obtained by an observation apparatus, and all possible observation outcomes are known before it takes place).[30] The probabilities $f_G^{(i)}$ $(i = 1, \ldots, R)$ are assigned to V_G realizations on the basis of G-KB, and the mental function assumes an expected value, $\bar{X}_{\boldsymbol{p},G} = \sum_{i=1}^{R} \chi_i f_G^{(i)}$, of the actual (but yet unknown) $X_{\boldsymbol{p}}$. At the *meta-prior* stage, the agent is exposed to S-KB. As a result, the probabilities $f_S^{(i)}$ $(i = l_1, \ldots, l_R)$ are assigned to a new subset V_S of realizations of $X_{\boldsymbol{p}}$. At the *posterior* stage, the $f_G^{(i)}$ and $\bar{X}_{\boldsymbol{p},G}$ are adapted in light of $f_S^{(i)}$, thus leading to new probabilities $f_K^{(i)}$ $(i = m_1, \ldots, m_R)$. Some realizations of V_G and V_S are eliminated, revised, or modified for consistency purposes. An updated expectation of the actual (but still unknown) $X_{\boldsymbol{p}}$ is obtained, $\bar{X}_{\boldsymbol{p},K} = \sum_{i=m_1}^{m_R} \chi_i f_K^{(i)}$. At the *actualization* (after the event) stage, one of the potentialities becomes the actual $X_{\boldsymbol{p}}$ value, in which case an assessment of the previous analysis can be made in terms, say, of the error $e = |X_{\boldsymbol{p}} - \bar{X}_{\boldsymbol{p},K}|$.

The reader has probably noticed that James' metaphor of the evolutionary process, powerful as it is in kindling one's creative imagination, is only partially true: Actualities sort of float in a wider sea of possibilities, but what is chosen from out of these possibilities is an approximation of actuality in a certain sense, whereas actuality itself most of the time escapes humans (until Nature reveals it after the event). In the evolutionary process above, probability lies in between potentiality and actuality, serving as the epistemic link between the two. Formal probability theory provides the tools to manipulate potentialities and the respective probabilities $f_G^{(i)}$ and $f_S^{(j)}$ once we have them. It should not escape the readers' attention, however, that where these probabilities come from and how they are determined is not the concern of formal analysis. These matters are linked to knowledge about the physical and other components of the problem (as these are expressed in terms of the G- and S-KB), as well as to the agent's reasoning skills (critical and creative), which is why they are the concern of stochastic calculus.

6.4 Vincere Scis, Hannibal-Victoria Uti Nescis[31]

It is argued that while mathematicians and statisticians devote significant time and talent in the development of a sophisticated theory, they devote much less effort to cultivate themselves within it or beyond it. Using a historical metaphor, the situation may remind one of General Maharbal's reproach to Hannibal, after the Carthaginian military leader had won a great victory against Romans at Cannae.

[30] Although, one must admit that the identification of the complete set of possibilities to be included in V_G may not be a straightforward affair in sciences such as medicine, especially since recognizing new symptoms, aggregating well-known symptoms in a novel way, and discovering unknown diseases are parts of an ongoing process enhancing the contents of V_G.

[31] "Truly, Hannibal, you know how to win a victory -but not how to *use* it."

Maharbal, who was Hannibal's cavalry commander, urged him to march to Rome immediately. At the very moment of his greatest triumph, and with ultimate victory almost at his fingerprints, Hannibal hesitated, in which case Maharbal told him: "Vincere scis, Hannibal-victoria uti nescis." Hannibal's indecision turned out to be his greatest blunder that led to his final defeat and the obliteration of Carthage by the Romans (Holland, 2009).

6.4.1 Changing the Way One Thinks One Does What One Does

In view of the discussion so far, a reasonable response to the two major problem-solution inadequacies identified in Section 2.3 could include two modeling postulates: (*a*) Since conventional system representation is an incomplete abstraction of reality, one should consider, instead, a stochastic representation that accounts for multisourced uncertainties of the in situ system and their interconnections. (*b*) The conception of a "solution" should assign different probabilities to possible space-time realizations, and focus on content-dependent knowledge synthesis rather than on formal processing in a strict sense. Problem-solvers should exhibit healthy amounts of creativity and innovation in an environment of uncertainty, and they may even need to change the way *they think they do what they do*. Among the disciplines that seem to be in a desperate need for such a change is epidemiology. In the first place, there is some confusion about the state of the field. On the one side, Dimitrios Trichopoulos, a Harvard epidemiologist, confesses that "People don't take us seriously…and when they do…we may unintentionally do more harm than good (Taubes, 1995: 164). In a similar spirit, Wasim Maziak (2008: 393) talks about the "credibility crisis brought about by inconsistencies in the results of various epidemiological studies (Whittmore and McGuire, 2003; Michels, 2003; Taubes, 1995). Increasingly, voices within and outside the discipline of epidemiology are calling for a total re-evaluation of its tools and paradigms, some going as far as to suggesting abandoning the field entirely (Susser and Susser, 1996; Le Fanu, 1999; Smith and Ebrahim, 2001; Lawlor et al. 2004; Buchanan et al. 2006; Pritchard, 2008)." Neil Pearce (2007) claims that the decline is profound "when the current state of epidemiology is assessed in terms of quality rather than quantity;" he goes on to attribute the decline of epidemiology to "the increasing role of corporate influences," among other things. On the other side of the hill, Kenneth J. Rothman (2007: 710) rejoices that "epidemiology today appears to be thriving… Epidemiology research, even when controversial, has gained respect in many quarters…a time of great opportunity in epidemiology." Also, David A. Savitz, Charles Poole and William C. Miller (1999) believe that "Criticisms that epidemiology fails to solve major public health problems … are unwarranted."

The implication of Postulate *a* above is that, with the exception of a few simple situations,[32] the formulation of an in situ system solely in terms of deterministic

[32] Say, closed systems with perfectly controlled environments.

mathematical equations is meaningless. Instead, the formulation should allow for alternative perspectives, thought experiments and metaphors, when appropriate. Subsequently, the implication of Postulate *b* is that the implementation of the term "solution" in the sense of the conventional formalism is of limited use in complex in situ problems. Rather the "solution" should be seen a mental construct that accounts for a large number of parameters and auxiliary assumptions of the open system; for mathematical concepts implicit in the equations representing the system, the way these concepts are linked to each other, and how the validity of the equations follows from the concepts; and for the creative influence of human reason that is of participatory nature, since the investigator is part of the solution process and one of the causes of what the solution will look like. Fortunately, the theory of simple ideas is under considerable suspicion nowadays.

This change in the conception of what constitutes a "solution" is a profound and fruitful one. In many disciplines this is a new conception that allows a new perception. Instead of claiming that one can view an in situ system without presumptive bias and derive a solution that is reality itself, one rather recognizes that the investigator's precedent assumptions influence and limit what kind of solution the investigator obtains. Therefore, another potentially significant departure from the standard paradigm is the thesis that a solution that assumes that the relevant model describes incomplete knowledge about Nature and focuses on cognitive mechanisms can yield better results than a mainstream, supposedly ontic solution, which assumes that the model describes Nature as is and focuses on form manipulations. In view of the above considerations, the empiricist claim that all concepts and ideas as well as the laws of Nature are always born out of empirical data analysis seems pure nonsense (see, also, Section 5.2.1). For example, it is hard to admit that the concepts of imaginary numbers or the n-dimensional geometry ($n > 3$) are products of experience, since one never observes these things in the real-world. Also, basic law of mechanics, such as the law of inertia, are never observed on Earth. This is why it was so difficult for scientists to disentangle the basic idea behind the inertia law. When this was made possible in terms of thought experiments and pure reasoning, rather than by means of observations, the door was opened to some of the greatest achievements in the world's history.

6.4.2 Waltz of Lost Dreams?

Stochastic reasoning and the associated calculus constitute a vital component of a inquiry process that seeks to apply logic to actual concepts rather than to pure symbols (which is the case of standard symbolic logic). As such, stochastic reasoning interacts with important notions like belief, uncertainty, probability, intentionality, awareness, and adaptation. In a Kantian sense, stochastic reasoning originates in thinking but necessarily applies in the world. It makes use of the tools of mathematical stochastics (Gardiner 1990; Christakos 1992; Shigekawa 2004) with three key distinctions: the implementation framework of these tools may vary considerably in stochastic reasoning, both contextually and contentually; stochastic reasoning is not limited to the use of the standard analysis tools; and at the heart of stochastic reasoning is awareness, fully experiencing the problem's environment and the human agent's role within it. In the IPS framework, stochastic reasoning attempts to synthesize different perspectives about a problem that is multithematic, multidisciplinary, multidirectional, multiempirical, and polychronic.

During times of introspection and inwardness, many theorists (scientific, philosophical etc.) may wonder whether their struggle with complex conceptual constructs and what many consider intimidating mathematics has meaning and purpose. Whether their conviction that "an unexamined world, a world not fully appreciated, is not worth living in" is of any relevance in today's socio-political environment of Decadence. Whether they can justify to themselves and to others the intellectual challenge and psychological mayhem their minds and souls experience during their attempts to go where "angels fear to tread." Whether the myriad tedious hours they spend in silent contemplation during their working days actually contribute to real-world problem-solving. Whether they will continue to find the courage to build roads with the stones the others cast at them. Whether it is worth developing a sense of awareness of their thoughts and actions that goes beyond doing things mechanically in a hurried and harried manner. Whether Plato's wisdom, *Ο άνθρωπος ο σοφὸς λέγει επεί τι λέγειν έχει, ο άνθρωπος ο μωρὸς επεί τι λέγειν αναγκάζεται*,[33] is sensical in a time of Decadence. Whether their intense dancing with abstract ideas, deep thoughts, and naked emotions is not a futile attempt to find truth, assign meaning, attribute purpose, and transcend the traumatic. And they are always concerned that, in the end, their lifelong undertaking would turn out to be a *waltz of lost dreams*. Inevitably, it is the charge of the individual theorist to answer such questions.

As was shown in Section 1.4 (on shadow epistemology), the elites who hold the information also get to interpret it. In ancient Greece the elite of so-called *archons* not only was the guardian of the most precious state documents (such as records, certificates, annals, and laws), but also had the power to interpret them in practice. As new archons, experimentalists in certain disciplines often refuse to share with theorists the available data so that they are free to interpret them at will. In this way they put their own narrow interests and professional egos above scientific progress and the common good. The situation looks bleaker if one adds to the above that most power holders within the system favor heavily experimental over theoretical research, because the resources required by the former are orders of magnitude larger than by the latter, thus allowing highly profitable "wheeling and dealing." Many theorists confess to each other that sometimes they feel that they are writing for the future (this is especially true in scientific disciplines at a weak state of development). As such, they are close to giving up hope that their contemporaries would abandon their ego-massaging designation, know-it-all arrogant attitude,

[33] The wise man speaks because he has something to say, the fool because he has to say something.

pseudo-practical mindset, and hostility to abstract thinking so that they can read theorists' work with open minds. Or is it rather for a new generation of investigators, unencumbered by the methodological burdens of the old that many theorists set their work for? Whatever their value, many theoretical IPS works would rather await fresh attention when the time is ripe. Past attempts to engage self-appointed "expert" practitioners of the theorists' own generation on their own ground proved futile. This is no worthwhile arena for many theorists. Even though the backbone of today's way of life is muddling through, there comes a time when circumstances are so unpleasant that muddling through may not work anymore. Then a theorist may have to fall back on reserve of inner strength, on principles, beliefs, and convictions.

Chapter 7
Operational Epibraimatics

Whenever a theory appears to you as the only possible one, take this as a sign that you have neither understood the theory nor the problem which it was intended to solve.

K. Popper

7.1 The Clouds of Dublin and the IPS Dualism

Any attempt to quantify the IPS postulates introduced in Section 3.5 is a challenging yet intriguing affair. The quantification should provide a description of the real-world situation that is close and at the same time at some distance to experience. These two complementary IPS requirements are indispensable in the development of a meaningful IPS approach that balances the significant values and potential limitations of human experience. In his effort to satisfy these requirements, the Irish novelist James Joyce provided an enlightening literary metaphor of *dualism*. In his novels, Joyce was able to describe people from *close-up* and also *out of a distance* by assuming an "indifference" position up in the clouds above Dublin.[1]

7.1.1 Theorizing and Correlating

Adequate appreciation of the role of dualism is, indeed, of critical importance in the quantification of the four IPS postulates. Dualism seeks to install Joyce's balance between experiencing appearances and engaging directly with events (close-up perspective), and distancing oneself from routine facts of "here and now" to place

[1] As portrayed in the stunning collection of photographs by Robert French, Joyce's Dublin was a city with spacious avenues, crowded backstreets and lively bandstands, trams and horse-drawn carriages, sailing ships and barges on the river Liffey. A city populated by every manner of person, well-heeled professional classes, women with perambulators, street vendors and gangs of urchins (Hickey 1982).

G. Christakos, *Integrative Problem-Solving in a Time of Decadence*,
DOI 10.1007/978-90-481-9890-0_7,

matters in a wider framework (out of a distance perspective). Using dualism as an IPS organizing principle harnesses both of these perspectives into a coherent and powerful whole. Accordingly, this chapter introduces a way to quantify the basic IPS postulates by means of a particular set of mathematical operators. The possibility to develop alternative sets of operators is an intriguing prospect, which is to say that Epibraimatics is a living practice rather than a determinate and unchangeable ensemble of dogmas and rules. Correspondingly, one more stage is now added to Eq. (3.2), as follows:

$$\left.\begin{array}{r}\text{Localised brain}\\ \text{activities}\end{array}\right\} \rightarrow \left.\begin{array}{r}\text{Mental}\\ \text{functions}\end{array}\right\} \rightarrow \left.\begin{array}{r}\text{Fundamental}\\ \text{posulates}\end{array}\right\} \rightarrow \\ \rightarrow \left.\begin{array}{r}\text{Mathematical}\\ \text{operators}\end{array}\right\} \rightarrow \text{Problem} - \text{Solutions.} \tag{7.1}$$

The sequence in Eq. (7.1) reveals the key role of mathematical modeling in IPS, without implying that this is the complete story. As we saw in previous chapters, at the one end of the spectrum there are thinkers who argue that what science can tell us comes from mathematical representations of the world. At the other end of the spectrum, some thinkers claim that we can learn about the world without using any mathematics or computing (in which case mathematical incompleteness problems are irrelevant to the limits of science). Surely, the usefulness of mathematics and its implementation in the study of natural systems should not be considered uncritically. However, when possible at all, the kind of scientific learning that excludes mathematical modeling has serious limitations in real-world problem-solving.

As soon as adequate operators are sought to quantify the IPS postulates, one may face the following dilemma: (a) either the agent uses theoretical modeling to probe reality, in which case one has to establish the congruence between the mathematical symbols, the conceptual entities, and the real-world observables; (b) or the agent abandons theorization altogether and simply correlates observations into some kind of empirical relationships expressing the regularities in the world. In option (a), one must come to terms with the fidelity of the model and issues of incompleteness that limit what the mathematics can say and do. In case (b), one must decide how to replace the notion of mathematical proof with a concept that expresses real-world truth. Option (b) is usually inadequate for well-documented reasons discussed in the literature (Section 2.5; also, Popper 1968; Medawar 1969; Wang 1993; Midgley 2004). Option (a) is favored by most scientists, but it should not be seen as a "black box" affair. The advantage of mathematics lies in its intellectual economy, in the sense that complicated logical operations are carried out without actual performance of the intellectual acts upon which the symbols rely. Some investigators argue that as soon as a thought becomes a tool, one can dispense with actually "thinking" it, i.e., with going through the logical acts involved in verbal or symbolic thought formulation. Such mechanization may be essential as regards the use of mathematics on a routine basis, but the Epibraimatics viewpoint is that mechanization should not become a central mind feature, because it then turns into a magical entity, an uninspiring habit that is blindly accepted rather than intellectually experienced. This habit leads to an instrumentalized and, hence, impoverished form of human reasoning, in which case the mathematical study of a natural system reminds one of a musical composition: once aspired to tell the world what it is and formulate an ultimate verdict, the musical composition is sometimes reified, with no living relation to the work in question, no direct, spontaneous understanding of its function as an expression, and no contextual framework.

7.1.2 IPS as Knowledge Synthesis

It is common practice that scientists try to apply a standard set of quantitative tools to a large variety of problems. One encounters many applications of computational methods in the study of physical systems, statistical techniques in biological problems, etc. Technical recipes and ad hoc data-fitting criteria are introduced in the study of diverse physical, biological, ecological, etc., systems. Much of statistical regression, e.g., consists of a set of techniques based on the criterion of minimizing the squared differences between the data and the solution (main justifications of the criterion are that it simplifies technical analysis and that it "works"[2]). Similar techniques are used in parameter estimation, hypothesis testing, and space–time prediction. When they fail to produce meaningful results, the reasons are searched in technicalities, curiously neglecting the possibility that the real reason may be that the techniques violate fundamental principles of scientific reasoning and epistemology (Section 9.4).

Building on the analysis in the previous sections, Epibraimatics seeks mathematical tools that can address the dualism premise. On theoretical grounds, a key issue is the prime role of investigator as a cause in the IPS process, the investigator being a rational agent (characterized by brain activities and mental functions). On practical grounds, the relevant equations could be thought of as *knowledge synthesis* rules, making epistemically sound calculations, and generating predictions of immediate consequence to the study of a natural system (predominantly space–time predictions that can be validated or refuted). Measurements (observations) are part of knowledge. They tell us about reality but are not reality themselves. A fusion of ideas from neuropsychological sciences (Chapter 3) can help IPS theorists derive novel concepts and quantitative tools that integrate technical "proof" (symbolic and numerical data processing) with everyday "truth" (contextual meaning and space–time interpretation) in a *living experience* setting. The above considerations open the possibility to conceive IPS as a network of databases, theories, beliefs, purposes, and thinking modes, in which

[2] The meaning of the term "works" is sometimes controversial.

any string in the net pulls and is pulled by the others in an interconnected way that can change the configuration of the whole.

7.2 The Value of Things

The quantification approach considered here involves certain basic concepts, such as uncertainty, probability, and information. We have already discussed in detail the first two concepts, which means that it is time to focus on the third one. Early on, Epibraimatics brings to the fore three noteworthy aspects of *information* and its relationship to human knowledge:

(a) *Technical and non-technical information*: The term "information" does not have the same significance to the non-scientist (an attorney or a police detective) and the scientist (a communication expert or a biologist). The non-scientists refer to some nontechnical use of the term (associated with entities like a legal document or a piece of evidence), whereas the scientists assign to the term a definite technical connotation (linked to mathematical or symbolic manipulations).

(b) *Information and meaning*: The entities the non-scientists deal with (e.g., all sorts of documents) usually have a certain meaning, whereas the entities the scientists consider (e.g., communication codes or optimization principles) may or may have not meaning (in the epistemic sense), but they still possess significant information (in the technical sense).

(c) *Information and uncertainty*: When it comes to the real-world, an investigator's knowledge of certain aspects of it has both meaning and uncertainty. The statement "a mission to Mars will be possible in the future," e.g., has meaning and a rather small (scientists hope) level of uncertainty. The statement "Mars is made of feta cheese," on the other hand, has meaning but an extremely high level of uncertainty.[3] Technical information focuses on the uncertainty aspect of knowledge. This is partially due to the fact that a mathematical description of "meaning" is not currently available. Hence, standard information notions provide a well-defined quantitative assessment of uncertainties linked to statements like the above, but offer no hint about their meaning.

7.2.1 The Boltzmann–Laplace Relationship

As early as the nineteenth century, Ludwig Boltzmann assigned a particular technical connotation to the notion of information when he associated the amount of uncertainty or disorder in a physical system with the lack of information about the

[3] To the considerable disappointment of Greek salad lovers.

actual structure of the system, and then he related the missing information with the *entropy* (S):

$$S = k \; \log W, \tag{7.2}$$

where W is the number of possible microstates linked to the macroscopic state of a system, and k is a physical constant (the logarithm has a natural base e). This historic formula, which launched the science of statistical mechanics, has been inscribed on Boltzmann's grave. In (7.2) entropy is not an absolute property of the system (like, say, its weight), but a relational property that depends on the information available about the system. Otherwise said, entropy measures an agent's incomplete knowledge about the detailed patterns of motions of the particles that constitute the system. This is yet another idea in the history of science that although it was logically derivable from theoretical considerations and the existing evidence, the limits of human imagination required a wealth of systematically acquired data to make the idea psychologically possible. The significance of Boltzmann's ideas is evident in the wealth of conceptual and technical resources it has generated across sciences. Another influential conception of information has its roots in the thoughts of another great man of science, Pierre–Simon Laplace. Laplace emphasized that beyond the probability of its occurrence, a realization of an entity[4] has some *utility* to the agent. An obvious way to express this utility is in terms of the information about the entity realization carried in the corresponding probability. It is surely intriguing to search for a relationship between Laplace's and Boltzmann's ideas in the general IPS context.

7.2.1.1 Trade-off Relationship Between Uncertainty and Probability

Consider an attribute S/TRF X_p with possibilities (realizations) χ_p. The search for a *Boltzmann–Laplace* (*B-L*) relationship starts with the uncertainty model of Eq. (4.9),

$$U_G(\chi_p) = U(P_G) = \lambda \log_a P_G^{-1}[\chi_p] = -\lambda \log_a P_G[\chi_p], \tag{7.3}$$

where the core knowledge base (G-KB) depends on the agent's epistemic situation, and λ is a constant that depends on the logarithmic base a. In Section 4.5.2, it was shown that formulation (7.3) is linked to the trade-off law asserting that the product of the probability P_G of χ_p and its uncertainty U_G cannot exceed a certain limit. Generally, (7.3) expresses a priori uncertainty associated with X_p about the occurrence of χ_p, or equivalently, the uncertainty contained in the model P_G about χ_p. As usual, the term "a priori" means that uncertainty considerations make sense only before the occurrence of χ_p (obviously, there is no uncertainty after the actualization of a potentiality).

[4] As before, the term "entity" may denote an attribute, process, phenomenon, or object.

7.2.1.2 The Uncertainty–Information Relationship

Let Eq. (7.3) be an a priori (before the event[5]) measure of uncertainty about the realization $\chi_{\boldsymbol{p}}$. After the event, when the realization actualizes, the uncertainty will be $U_G = U(1) = K \log 1 = 0$. Hence, one may view the uncertainty reduction before and after the event as expressing the information $I_G(\chi_{\boldsymbol{p}})$ contained in a realization $\chi_{\boldsymbol{p}}$ of the attribute $X_{\boldsymbol{p}}$ with probability $P_G[\chi_{\boldsymbol{p}}]$, i.e.,

$$I_G(\chi_{\boldsymbol{p}}) = U_G^{\text{Before the event}} - U_G^{\text{After the event}} = -\lambda \log_a P_G[\chi_{\boldsymbol{p}}], \tag{7.4}$$

where the constant λ determines the information unit,[6] and uncertainty is defined in the technical sense (7.3). Equivalently, the uncertainty reduction could be seen as the information $I_G(P_G)$ carried in P_G about $\chi_{\boldsymbol{p}}$, viz., $I_G(\chi_{\boldsymbol{p}}) = I_G(P_G)$. The agent considers all information calculations at the a priori stage, since these calculations only make sense before the actual occurrence of a specific realization. In the familiar example of flipping a coin, (7.4) answers a yes/no question: Will the coin land "heads" or not? Before the coin lands, the agent does not know the answer and is in a state of uncertainty (linked to the probability assigned to "heads"). When the coin lands the answer (yes/no) eliminates the agent's uncertainty. The difference between the two states of uncertainty (before and after the coin lands) is information. Equation (7.4) may be seen as a Boltzmannian formulation of the Laplacian notion concerning a realization's utility to the agent. The B–L relationship (7.4) has a formal component represented by the equation symbols, and an interpretive component expressed by the meaning assigned to the symbols and their mutual associations.

Before leaving this section, it is intriguing to imagine oneself on the top of "Joyce's clouds," and gaze at the B–L relationship from different directions. The first thing one notices is that information (7.4) expresses an inverse law: Given a *G*-KB, the fewer possibilities a probability model P_G permits concerning the $X_{\boldsymbol{p}}$ realizations, the more informative the model is. Another thing one notices is that an attribute's utility to the agent is expressed quantitatively in terms of the information I_G about each $\chi_{\boldsymbol{p}}$ carried in P_G. Which brings us to the study of the technical and contextual features of information (7.4). These conceptual and technical features co-exist in a generative tension. Thinking about the former can stretch one's understanding of the latter, and vice versa.

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[5] The term "event" may refer to an experiment, an observation, or any other source of knowledge concerning the entity.

[6] Depending on the logarithmic base, various information *units* are used. The most commonly used base is 2, in which case $\lambda = 1$ and the unit is $\log_2 2 = 1$ *bit* (from *bi*nary digi*t*). When the base e is used the information unit is called *nat* (*na*tural uni*t*) and one writes $\log_e \chi = \ln \chi$. With respect to any base a it is true that $\log_a \chi = (\ln a)^{-1} \ln \chi \geqslant (\ln a)^{-1}(1 - \chi^{-1})$ and, by convention, $\log_a 0 = \infty$ and $0 \log_a 0 = 0$. Unless otherwise noticed, herein the base 2 will be assumed, in which case we let $\log_2 = \log$ for simplicity.

7.2.2 Technical Features of Information

A few simple illustrations of Eq. (7.4) could throw some light on the B-L relationship and its implementation. The readers may recall that the technical information introduced by (7.4) deals with the uncertainty aspect of knowledge, but not with its meaning. Some of the distinct features of technical information and the associated insights are summarized in Table 7.1. Uncertainty (due to incomplete datasets, imperfect modeling, etc.) initiates the process of information seeking. Intuitively, the more probable a realization $\chi_{\boldsymbol{p}}$ of an attribute $X_{\boldsymbol{p}}$ is, the less uncertain is its occurrence. Hence, it makes sense to use the monotonically decreasing function (7.3) as a measure of uncertainty about $\chi_{\boldsymbol{p}}$. The proportionality relationship between uncertainty and information implies that Eq. (4.39) can be replaced by $P_G\, I_G \leqslant c$; i.e. the product of the probability P_G of $\chi_{\boldsymbol{p}}$ and the information I_G about $\chi_{\boldsymbol{p}}$ carried in the model P_G (sometimes termed the model's informativeness) cannot exceed a certain limit (there is a trade-off between information and probability). The area under the curve $I_G(P_G)$ is $-c \log P_G$, i.e. the technical information carried in P_G about $\chi_{\boldsymbol{p}}$ is proportional to $-\log P_G$, which is Eq. (7.4).

The statement "the attribute realization $\chi_{\boldsymbol{p}}$ is a priori certain to occur" clearly implies that $P_G[\chi_{\boldsymbol{p}}] = 1$, in which case Eq. (7.4) gives $I_G = \log(1) = 0$: the information contained in a certain realization (a realization with probability 1) is 0. Alternatively, one could say that the uncertainty associated with attribute $X_{\boldsymbol{p}}$ that has only one realization is 0. If $X_{\boldsymbol{p}}$ has N a priori equiprobable realizations, then $P_G[\chi_{\boldsymbol{p}}] = N^{-1}$, and Eq. (7.4) gives $I_G = \log N$: the information carried in P_G about each realization is the same and equal to $\log N$. Correspondingly, the larger the number of possible realizations, the larger the information carried in P_G (and the larger the uncertainty associated with $X_{\boldsymbol{p}}$). In the case of stochastic independence, $I_G(\chi_{\boldsymbol{p}_1} \wedge \chi_{\boldsymbol{p}_2}) = I_G(\chi_{\boldsymbol{p}_1}) + I_G(\chi_{\boldsymbol{p}_2})$, which is consistent with the uncertainty additivity condition (Section 4.5.2). Now let $X_{\boldsymbol{p}}$ denote the temperature at $\boldsymbol{p} = (\boldsymbol{s},\ t) =$ (Athens, April 4, 2011), and consider two a priori equiprobable realizations at $\mathbf{p}$: "$\chi_{\boldsymbol{p}}^{(1)} \geqslant 28^0\, C$" and "$\chi_{\boldsymbol{p}}^{(2)} < 28^0\, C$," i.e. $P_G[\chi_{\boldsymbol{p}}^{(1)}] = P_G[\chi_{\boldsymbol{p}}^{(2)}] = \frac{1}{2}$. After the event "$\chi_{\boldsymbol{p}}^{(2)}$ occurred" (S-KB), $P_K[\chi_{\boldsymbol{p}}^{(2)}] = 1, K = GUS$. According to the preceding analysis, the amount of technical information about $\chi_{\boldsymbol{p}}^{(2)}$ is $I_K(\chi_{\boldsymbol{p}}^{(2)}) = \log\left(\frac{1}{2}\right)^{-1} - \log\,(1)^{-1} = \log 2 = 1$ bit. Note that the information about $\chi_{\boldsymbol{p}}^{(1)}$ is $I_K(\chi_{\boldsymbol{p}}^{(1)}) = \log\left(\frac{1}{2}\right)^{-1} - \log\,(0)^{-1} = -\infty$ bits. This is a formally correct but meaningless result, since in the real-world the information concept has meaning only "before the event" (when one does not know the actual outcome). Hence, in a technical sense, to consider the "before the event" possibility of either of the two realizations becoming true is $I_G(\chi_{\boldsymbol{p}}^{(1)}) = I_G(\chi_{\boldsymbol{p}}^{(2)}) = 1$ bit.

Table 7.1 Technical features of information

Is concerned with the technical sense of the term "uncertainty" and not with its meaning.
Is inversely proportional to the probability of an attribute realization.
Is considered in terms of either a specific realization or an ensemble of realizations.
Is contained in a realization or carried in the associated probability model.

7.2.3 Contextual Features of Information

The readers are now prepared to see for themselves some of the main features of the setting within which the information concept is considered (Table 7.2). Although many of the mathematical formulas are well known, Epibraimatics suggests exploring alternative ways to interpret them. One could use psychological notions to interpret "information," such as the contextual ignorance and surprise of the agent (due to limitations of mental constructs, gaps in meaning, etc.). Accordingly, the information in Eq. (7.4) can be viewed as the difference in agent's *ignorance* (Ign_G) before and after the event:

$$I_G(\chi_{\boldsymbol{p}}) = Ign_G(P_G) - Ign_G(1) = -\lambda \log_a P_G[\chi_{\boldsymbol{p}}], \tag{7.5}$$

since $Ign_G(1) = 0$. Otherwise said, information is a *difference that makes the difference*. In a similar psychological setting, information may be seen as the agent's *surprise* before and after the event. The readers would notice that two notions with psychologically opposite meanings, ignorance and information, have the same formal representation. Moreover, the inverse relationship between probability and information seems to be justified on psychological grounds, in addition to the technical grounds considered in the previous sections. According to Daniel Gilbert (2005: 220), psychological experiments have shown that the least probable experience is often considered the most informative by the agent, on the grounds that it is the most likely experience for one to remember. It has also been suggested that the association of information with probability has evolutionary precedents. Steven Pinker (1997), e.g., argued that one would expect organisms, especially informavores such as humans, to have evolved acute intuitions about probability. In evolutionary terms, survival depends on a living organism's ability to gather and process information. A passive mind is of no help, as far as breeding, development, and survival of the species is concerned.

One may also look at the information concept in terms of *worthiness*. Let the entity $X_{\boldsymbol{p}}$ include a priori N realizations that obey the probability model P_N. Consider the event, "a report R becomes available that reduces the number of possible realizations to n ($<N$) obeying a new model P_n." The worthiness of the report to the agent is expressed as the amount of information the report R offers to the agent:

Table 7.2 Contextual features of information

Refers to a specified context (experimental setup or modeling framework) that generates a number of possible realizations.
Makes sense in an a priori setting.
Level of information sought depends on the problem.
May assume cognitive or psychological interpretations (ignorance, surprise, etc.).
May measure the worthiness of a certain KB (event, fact, or law) to the agent.
Same amount of information may have different value to different agents or under different circumstances.

$$I_G(R) = U(P_N) - U(P_n) = -\log\left(P_N P_n^{-1}\right) = \log P_{N,n}^{-1}, \tag{7.6}$$

where $U(P_N) = \log P_N^{-1}$ is the uncertainty about a realization before R becomes available, $U(P_n) = \log P_n^{-1}$ is the uncertainty linked to R, and $P_{N,n} = P_N P_n^{-1}$ is the final probability following the integration of prior knowledge with the report. In the special case of equiprobable realizations, $P_N = N^{-1}$, $P_n = n^{-1}$, $P_{N,n} = \frac{n}{N}$. The readers may notice a formal difference between Eqs. (7.5) and (7.6): the first equation involves the probability model (P_G), whereas the second starts with an original model (P_N), which is subsequently updated in light of an intermediate model (P_n) to yield the final model ($P_{N,n}$). In Section 7.3, we will further develop this distinction by considering an IPS approach that blends G-based probability models P_G with S-based models P_S to yield the final P_K, $K = G \cup S$. As should be expected, these equations also show that the investigator's information state basically makes sense in an a priori context (when the "after the event" actualization of the realization is purely hypothetical), in which case information is expressed as the agent's uncertainty reduction before and after the hypothetically certain event. This event is a priori an existing option (e.g., a worthy piece of knowledge about the "after the event" situation already exists that is of certain worth to the agent).

Not surprisingly, different disciplines interpret information in distinct, and sometimes contradictory, contexts (Derudie 1992; Webster 1995; Hill 1999; Stiglitz 2000; Fenner 2002). In economics, information is considered as uncertainty reduction and is measured in terms of exchange rates of supply and demand. In accounting, information is linked to costs and profits. Sociology is concerned with the net public good of information, whereas behavioral science focuses on cognitive and behavioral change due to information.[7] In this book, the information concept is used for TP quantification purposes in a suitable space–time context (Section 7.3.3); the relative importance of the G- and S-KBs (in an informational sense) is assessed in Section 7.5; and the explanatory power of different models may be studied using space–time information functions (Chapter 8).

7.2.4 *It Is Not Where One Takes Things from, It Is Where One Takes Them to*

The original information definition (7.4) can be mathematically manipulated to generate new formulations; and it can allow new interpretations of old formulations.

[7] It is noteworthy that there exist several other possibilities concerning the mathematical definition of information, which are discussed, e.g., in Aczel and Daroczy (1975).

7.2.4.1 Expected Information as Entropy

Often what is of interest is the *expected* (*average* or *potential*) information associated with $X_{\boldsymbol{p}}$, generally defined as (attribute with discrete values)

$$\overline{I_G} = -\lambda \sum\nolimits_{i=1}^{N} P_G[\chi_{\boldsymbol{p}_i}] \log_a P_G[\chi_{\boldsymbol{p}_i}] = -\lambda \sum\nolimits_{i=1}^{N} \beta_{\boldsymbol{p}_i} \log_a \beta_{\boldsymbol{p}_i}, \tag{7.7}$$

where $P_G[\chi_{\boldsymbol{p}_i}] = \beta_{\boldsymbol{p}_i} \in [0,\ 1]$. Equation (7.7) refers to the amount of expected information carried in P_G about the set of possible realizations $\chi_{\boldsymbol{p}_i}$ $(i = 1, \ldots, N)$, or equivalently, the amount of uncertainty contained in P_G about these realizations. The continuous case of (7.7) will be considered in an S/TRF setting (Section 7.25 below).

The mathematical formulation (7.7) was introduced in the late 1940s by Claude Shannon for communication engineering purposes. Correspondingly, its interpretation was in terms of description, storage, and transmission of messages (Shannon and Weaver 1948). It is noteworthy that (7.7) is also known as the *entropy* $\varepsilon_G = \overline{I_G}$ of $X_{\boldsymbol{p}}$. This is because Eq. (7.7) bears a formal resemblance to the entropy of statistical mechanics (introduced by Boltzmann in the nineteenth century).[8] Which is why Eq. (7.7) is often referred to as the *Boltzmann–Shannon* (*B–S*) entropy, despite the fact that the original statistical mechanics interpretation of entropy is substantially different from interpretations that were derived at later times and possess their own invaluable authenticity. *Inter alia*, the expected information (entropy) of Eq. (7.7) has been used in neurosciences to explain variations in hippocampal responses. The preceding theoretical analysis seems to be supported by experimental data suggesting that hippocampal neuronal activity is dictated by the probabilistic structure of the environment with activity in this region representing the expected information of an event before it occurs (Strange et al. 2005: 229).

7.2.4.2 Comparing Entropies

It is instructive to compare the original entropy (7.2) with the information-theoretic entropy (7.7) on interpretive grounds. Leon Brillouin (1956) has shown that Eq. (7.2) can be also written as $S = -k \sum_{i=1}^{N} \beta_i \log_a \beta_i$, where β_i are suitable probabilities associated with the microstates of the system considered. However, there is an important difference: while Boltzmann's constant k in Eq. (7.2) has a definite physical meaning (scales thermal energy), the constant λ in Eq. (7.7) merely determines the unit of information. A detailed analysis of the substantive differences between the two entropies can be found in the literature, where alternative entropy meanings are also considered (Wicken 1987; Yockey 1992;

[8] According to Max Planck, "[t]he logarithmic connection between entropy and probability was first stated by Ludwig Boltzmann in his kinetic theory of gases."

Ebanks et al. 1998; Bradley 2004). In the end, when it comes to matters of originality, meaning, and interpretation, a quote by Jean-Luc Godard, one of the founders of the *Nouvelle Vague*, seems appropriate:

> It's not where you take things from, it's where you take them to.

A key distinction should be made between information I_G and average information (entropy) $\overline{I_G}$. On the one hand, $I_G(\chi_p)$ is the information contained in the realization χ_p of an attribute X_p with probability $P_G[\chi_p]$, or the information $I_G(P_G)$ carried in P_G about χ_p. Alternatively, $I_G(\chi_p)$ expresses the uncertainty about the occurrence of χ_p, or the uncertainty contained in P_G that is associated with χ_p. On the other hand, $\overline{I_G}$ is the average information carried in P_G that is associated with the set of possible realizations of X_p, or the average information per realization contained in this set. Alternatively, $\overline{I_G}$ expresses the uncertainty contained in P_G about the set. To clarify some of these notions, let us study the following example by Leon Brillouin (1956). Assume that the 27 symbols of the English language (26 letters of the alphabet plus the "word space" or "blank" as symbol) have equal a priori probabilities to occur in a sentence. The a priori information provided by each symbol is $I_G = \log\left(\frac{1}{27}\right)^{-1} = 4.76$ bits/symbol, which is also the expected information (entropy) per symbol, i.e., $\overline{I_G} = 4.76$ bits/symbol. The actual a priori probabilities of these symbols occurring in sentences are, $P_G[\text{blank}] = 0.2$, $P_G[A] = 0.063$, $P_G[L] = 0.029$, $P_G[X] = 0.002$, etc. The corresponding a priori information amounts provided by the symbols are, respectively, $I_G[\text{blank}] = 0.699$, $I_G[A] = 1.2$, $I_G[L] = 1.54$, $I_G[X] = 2.7$ bits/symbol etc.[9] In this case, the expected or average information (entropy) per symbol (for all 27 symbols) is $\overline{I_G} = -\sum_{i=1}^{27} P_G[\text{symbol}_i] \log P_G[\text{symbol}_i] = 4.03$ bits/symbol. Finally, since the sequence of symbols in sentences in not random, one can also account for spatial connections between symbols (e.g., nearest neighbor influences), thus obtaining $\overline{I_G} = 3.32$ bits/symbol.

At this point, some conclusions could be drawn. Additional knowledge concerning X_p would reduce the uncertainty about χ_p carried by the corresponding P_G model (the number of possible realizations is decreased as more knowledge about the attribute becomes available). The information framework is based on three basic items: the attribute X_p; attribute realizations χ_p with specified probabilities; and the probability model $P_G[\chi_p]$ of X_p that carries an amount of information about each realization.

7.2.5 *Entropy in a Space–Time Continuum*

Form expresses relationships across space–time under conditions of uncertainty, and this insight carries over into the concept of information, which makes it natural

[9] The complete list for all 27 symbols can be found in Brillouin (1956).

to extend the above results in a composite space–time continuum. Let $\chi_{\boldsymbol{p}}$ be a realization of the attribute S/TRF $X_{\boldsymbol{p}}$, and let $f_G(\chi_{\boldsymbol{p}}) = f_{G,\boldsymbol{p}}$ be its PDF in light of G-KB. The expected information (entropy) associated with $X_{\boldsymbol{p}}$ in the space–time continuum is:

$$\varepsilon_{G,p} = \overline{I_{G,\boldsymbol{p}}} = \int d\chi_{\boldsymbol{p}} f_{G,\boldsymbol{p}} \log f_{G,\boldsymbol{p}}^{-1}. \tag{7.8}$$

Eq. (7.8) expresses the information carried in the PDF model about the set of all possible realizations $\chi_{\boldsymbol{p}}^{(1)}, \ldots, \chi_{\boldsymbol{p}}^{(R)}$ of $X_{\boldsymbol{p}}$. Or equivalently, (7.8) expresses the uncertainty $\varepsilon_{G,\boldsymbol{p}} = \overline{\log f_{G,\boldsymbol{p}}^{-1}}$ of an agent about the set of possible realizations of $X_{\boldsymbol{p}}$.

Since different models $f_{G,\boldsymbol{p}}^{(i)}$ may be associated with an S/TRF, the sets R_i of possible S/TRF realizations allowed by each model may differ as well. For illustration, consider two possible models $f_{G,\boldsymbol{p}}^{(i)}$ $(i = 1,\ 2)$ of $X_{\boldsymbol{p}}$. Assume that the corresponding sets of realizations allowed by $f_{G,\boldsymbol{p}}^{(1)}$ and $f_{G,\boldsymbol{p}}^{(2)}$ are such that $R^{(1)} < R^{(2)}$.[10] It is more likely that one of the realizations of $R^{(2)}$ rather than of $R^{(1)}$ will actually occur. In this sense, the set $R^{(2)}$ is more certain than $R^{(1)}$. *A contrario*, by allowing more realizations, the model $f_{G,\boldsymbol{p}}^{(2)}$ is less informative than $f_{G,\boldsymbol{p}}^{(1)}$ (the entropy of the former model is smaller than that of the latter).[11] Speaking to the point, the way the entropy concept is used in S/TRF analysis depends on the milieu within which entropy is considered. Given a G-KB about $X_{\boldsymbol{p}}$, if the outcome (set of realizations) with the maximum average information is sought, the PDF model with the highest $\varepsilon_{G,\boldsymbol{p}}$ should be considered. If, on the other hand, the most certain outcome is sought, the PDF model with the lowest $\varepsilon_{G,\boldsymbol{p}}$ would be the study focus. Again, the above technical analysis finds theoretical and experimental support in the brain and neuropsychological sciences. According to a school of thought one of brain's adaptive features is keeping under control the range of possible states the agent can occupy in order to avoid risky states (Section 3.5.1). An agent could even consider the mental image of a probability distribution that assigns different likelihoods to these states and the brain's desire for a highly informative distribution.

Since the attribute $X_{\boldsymbol{p}}$ varies across space–time, its entropy varies across all combinations of space–time points as well. So, an investigator may consider the entropy at a specified space–time point ($\boldsymbol{p} = \boldsymbol{p}_1$ and $d\chi_{\boldsymbol{p}} = d\chi_{\boldsymbol{p}_1}$ in (7.8); or between two points $\boldsymbol{p} = (\boldsymbol{p}_1, \boldsymbol{p}_2)$ and $d\chi_{\boldsymbol{p}} = d\chi_{\boldsymbol{p}_1}\, d\chi_{\boldsymbol{p}_2}$), i.e.,

[10] For example, $R^{(i)} = \{\chi : \chi \in [a_i,\ b_i]\}$, $i = 1,\ 2$; $|a_1 - b_1| < |a_2 - b_2|$.

[11] A distinction is made between realization probabilities (probabilities the models $f_{G,\boldsymbol{p}}^{(1)}$ and $f_{G,\boldsymbol{p}}^{(2)}$ assign to each one of the $R^{(1)}$ and $R^{(2)}$ attribute realizations) vs. model probabilities (probability of each one of the models $f_{G,\boldsymbol{p}}^{(1)}$ and $f_{G,\boldsymbol{p}}^{(2)}$ turning out to be correct). There are $R^{(1)}$ and $R^{(2)}$ individual probabilities within $f_{G,\boldsymbol{p}}^{(1)}$ and $f_{G,\boldsymbol{p}}^{(2)}$, respectively. But there is one global probability for $f_{G,\boldsymbol{p}}^{(1)}$ and one for $f_{G,\boldsymbol{p}}^{(2)}$. Since $f_{G,\boldsymbol{p}}^{(2)}$ allows more realizations than $f_{G,\boldsymbol{p}}^{(1)}$ $(R^{(2)} > R^{(1)})$, $f_{G,\boldsymbol{p}}^{(2)}$ may assign lower probabilities to any one of the $R^{(2)}$ realizations than does $f_{G,\boldsymbol{p}}^{(1)}$ to any one of its $R^{(1)}$ realizations (total probability for both sets of realizations is 1). On the other hand, the probability that model $f_{G,\boldsymbol{p}}^{(2)}$ (global probability) will be correct (in the sense that one of the realizations it allows will actually occur) is higher than that of model $f_{G,\boldsymbol{p}}^{(1)}$.

$$\varepsilon_{G,\boldsymbol{p}_1,\boldsymbol{p}_2} = \overline{I_{G,\boldsymbol{p}_1,\boldsymbol{p}_2}} = \int d\chi_{\boldsymbol{p}_1} d\chi_{\boldsymbol{p}_2} f_{G,\boldsymbol{p}_1,\boldsymbol{p}_2} \log f^{-1}_{G,\boldsymbol{p}_1,\boldsymbol{p}_2}. \tag{7.9}$$

Equation (7.9) expresses the amount of information carried in the PDF model about the set of possible realization pairs $(\chi_{\boldsymbol{p}_1}, \chi_{\boldsymbol{p}_2})$ of $X_{\boldsymbol{p}}$ at $\boldsymbol{p}_1$ and $\boldsymbol{p}_2$; or equivalently, the agent's uncertainty about the set of all realization pairs at these points. One may assume that at large lags $(\boldsymbol{s}_2 - \boldsymbol{s}_1,\ t_2 - t_1 \to \infty)$ stochastic independence is valid, $f_{G,\boldsymbol{p}_1,\boldsymbol{p}_2} = f_{G,\boldsymbol{p}_1} f_{G,\boldsymbol{p}_2}$, in which case (7.9) yields $\varepsilon_{G,\boldsymbol{p}_1,\boldsymbol{p}_2} = \varepsilon_{G,\boldsymbol{p}_1} + \varepsilon_{G,\boldsymbol{p}_2}$. Moreover, *conditional* entropy is defined as[12]

$$\varepsilon_{G,\boldsymbol{p}_1|\boldsymbol{p}_2} = \overline{I_{G,\boldsymbol{p}_1|\boldsymbol{p}_2}} = \overline{\log f^{-1}_{G,\boldsymbol{p}_1|\boldsymbol{p}_2}}. \tag{7.10}$$

Multipoint entropies of an attribute involving several space–time points may be also defined, which refer to the amount of information about the set of realizations $\chi_{\boldsymbol{p}_1}, \ldots, \chi_{\boldsymbol{p}_k}$ of $X_{\boldsymbol{p}}$ at the points $\boldsymbol{p}_1, \ldots, \boldsymbol{p}_k$; as well as multiple-attribute entropies that involve several interrelated attributes $X_{1,\boldsymbol{p}}, \ldots, X_{n,\boldsymbol{p}}$ (Christakos 1992, 2000). Equation (7.8) is one possible way to define $\varepsilon_{G,\boldsymbol{p}}$, but Epibraimatics is not limited to the B–S entropy, $\varepsilon_{G,\boldsymbol{p}} = \varepsilon^{B-S}_{G,\boldsymbol{p}}$. Rather its methodological framework remains valid if alternative definitions of $\varepsilon_{G,\boldsymbol{p}}$ are used, including the Fisher, Renyi, and Tsallis entropies (Renyi 1961; Frieden 1999; Tsallis 1988) properly extended in the spatiotemporal IPS domain (Table 7.3). As a matter of fact, Epibraimatics encourages investigators to study different entropy models, since a comparative study can provide them with a perspective from which to assess current interpretations of the information notion and, if necessary, develop new ones.

7.2.6 What Herodotus Knew

As noted earlier, beyond the probability of its occurrence, a possible attribute realization has a value to the agent expressed in terms of the information about

Table 7.3 Types of entropy (measures of expected information)

Boltzmann–Shannon (B–S)	$\varepsilon^{B-S}_{G,\boldsymbol{p}} = \int d\chi_{\boldsymbol{p}} f_{G,\boldsymbol{p}} \log f^{-1}_{G,\boldsymbol{p}}$
Fisher (F)	$\varepsilon^{F}_{G,\boldsymbol{p}} = \int d\chi_{\boldsymbol{p}} f_{G,\boldsymbol{p}} \sum_i \left(\frac{d}{d\chi_{\boldsymbol{p}_i}} \log f_{G,\boldsymbol{p}}\right)^2$
Renyi (R)	$\varepsilon^{R}_{G,\boldsymbol{p}} = (1-\alpha)^{-1} \log\left(\int d\chi_{\boldsymbol{p}} f^{\alpha}_{G,\boldsymbol{p}}\right),\ \alpha>0$
Tsallis (T)	$\varepsilon^{T}_{G,\boldsymbol{p}} = (q-1)^{-1}\left(1 - \int d\chi_{\boldsymbol{p}} f^{q}_{G,\boldsymbol{p}}\right) = \int d\chi_{\boldsymbol{p}} f_{G,\boldsymbol{p}} \log_q f^{-1}_{G,\boldsymbol{p}},\ q \in R$

$\log_q\left(e_q^{\log_q c}\right) = c$; in the limit, $\varepsilon^{R}_{G,\boldsymbol{p}}, \varepsilon^{T}_{G,\boldsymbol{p}} \xrightarrow{q \to 1} \varepsilon^{B-S}_{G,\boldsymbol{p}}$

[12] Here, $\overline{\log f^{-1}_{G,\boldsymbol{p}_1|\boldsymbol{p}_2}} = \int d\chi_{\boldsymbol{p}_1} f_{G,\boldsymbol{p}_1|\boldsymbol{p}_2} \log f^{-1}_{G,\boldsymbol{p}_1|\boldsymbol{p}_2}$.

the realization carried in the corresponding probability. But does this information itself have a *value*, and if it does, how is it measured? Herodotus, the world's first historian, knew that the world is an infinite place that varies considerably from one place to another, and that "one man's truth might easily be another's lie." In certain cases, a piece of information may have a specified value to an agent that differs considerable from the value it has to another agent. For example, while there is the same amount of technical information in a statement about someone's wife having a boy or a girl as in a statement that your own wife is having a boy or a girl, in the second case the value of the information is of much greater value and importance to you. This value is not captured by the technical B–S theory that refers to syntactic information and focuses rather on structural relationships between entity values. Indeed, a phrase from the Homeric poem "Odyssey" can have the same amount of information, in the technical sense, as a phrase of street poetry.

The main reason for the apparent paradoxes in the above examples is that the standard information theory is not concerned with meaning, but it deals with shape and statistical ensembles of possible attribute realizations. The classical B–S information depends only on the shape of the probability distribution. For example, if the spread of a major disease and the increase of football fans in a region obey the same probability model, then the information associated with the occurrence of either event is the same. In some other cases, the value of information may be linked with situations in which what prevents the flow of knowledge can be a source of information itself. By noting, e.g., which are the entities that obstruct knowledge of the actual cause of a phenomenon one can obtain valuable information about the phenomenon. Then, a key issue is how one can conceptualize and quantify the value of this sort of indirect information. Other disciplines (economics, finance, management, etc.) have used the price system to assign value to information (Bradford and Kelejian 1977; Wood 1985; Lawrence 1999), but this approach is far from being an adequate solution to the information value problem (Goldman 1967). Clearly, it is not sufficient to view the information value situation as yet another problem to which one can apply the existing methods and techniques. Developing an information theory that is based on *meaning* and expresses quantitatively the information's value to an agent could be a highly sought development. Such a theory would involve not merely the probabilities of attribute realizations, but also their possible consequences, in which case the theory could be useful in describing the value of information and the importance of uncertainty to an agent, a group of citizens, or an expert decision maker. Perhaps, this kind of information theory will need the development of a new kind of mathematics that is not a purely formal construct but has *extra-formal* features as well. The prime purpose of mathematics would then be to obtain symbolic representations of certain human states and private experiences (like the content of feelings, personal values, qualia, instincts, etc.) to which formal mathematics can be implemented. At the same time, the claims emerging from the symbolic representations should be verified by rational reflection on the contextual conditions and contents of living experience. Whether this is possible or not at the current stage of human inquiry, one cannot answer with certainty.

7.3 Quantification of the Postulates: Fusing Form and Content

To account for important theoretical representations of mental functions in the derivation of an IPS, one needs to take an interest in what goes inside the brain as well as in the observable and measurable behavior combined with cognitive techniques. Chapter 3 revisited ideas and methods of neuropsychological science, which led to the development of certain postulates that an IPS approach could be based upon. Adequate quantification of these postulates is an intriguing yet challenging affair. It is intriguing, because it engages the interest of real-world problem-solvers who are open to new ideas or just to ordinary ones seen from a new angle. And it is challenging, because it requires the fusion of form and content into an indivisible whole. One way to quantify the IPS postulates by means of a particular set of mathematical operators is discussed below. Yet, these operators do not constitute a *conditio sine qua non*.[13] Probably they are not the only ones that can do the job, and may not even be the best ones. The possibility of alternative operators is worth investigating by the inquisitive minds of the interested readers.

7.3.1 The Plurality Concept: Learn from the Future Before It Happens

Voltaire once famously said that, "The present is pregnant with the future." In a literary spirit, the complementarity postulate (CoP, Section 3.5.1) suggests using the presently "pregnant state" of a creative mind as a basis for substantive theorizing about the unknown future. The insight offered by CoP is that a model of the in situ system should consist of a plurality of possibilities (realizations). Interestingly, the CoP seems to be in agreement with the ancient skeptics' perspective that human inquiry should go through a "what-if" stage, which considers various possibilities before it is able to generate useful knowledge.

7.3.1.1 Formal Expression and Visual Representation

The quantitative assessment and description of the multisourced system uncertainty and space–time variability of a system is made with the help of stochastic reasoning (Chapters 5 and 6). The starting point is the formal expression (see, also, Eq. (5.8))

[13] Condition without which not.

$$\chi_p \xrightarrow[\text{reasoning}]{\text{Stochastic}} X_p \sim \left\{ \begin{array}{r} f_{X_p} \\ DF_{X_p} \end{array} \right\} \rightarrow \left\{ \begin{array}{l} \chi_p^{(1)} \ with\ probability\ P_{KB}^{(1)} \\ \chi_p^{(2)} \ with\ probability\ P_{KB}^{(2)} \\ \quad \vdots \\ \chi_p^{(R)} \ with\ probability\ P_{KB}^{(R)} \end{array} \right. , \qquad (7.11)$$

where f_{X_p} is the attribute PDF that takes into consideration all available KBs, and DF_{X_p} denotes the corresponding space–time dependence functions (Section 5.7). The meaning of Eq. (7.11) is that a rational agent ought to adopt a stochastic rather than a deterministic perspective concerning the system of interest. In other words, the agent should favor replacing the unrealistic certainty of a rigid mind with the mental functions of creative uncertainty. This decision has far-reaching implications in the IPS setting and its potential applications.

In light of Eq. (7.11), a visual representation of the S/TRF X_p is attempted in Fig. 7.1. As we saw in Section 5.3, by assuming a plurality of possible realizations (parallel worlds), the random field model requires the consideration of that which (probably) *does not exist* in order to explain that which *actually exists* (but is unknown to the agent). The coexistence of structure (causality) and randomness

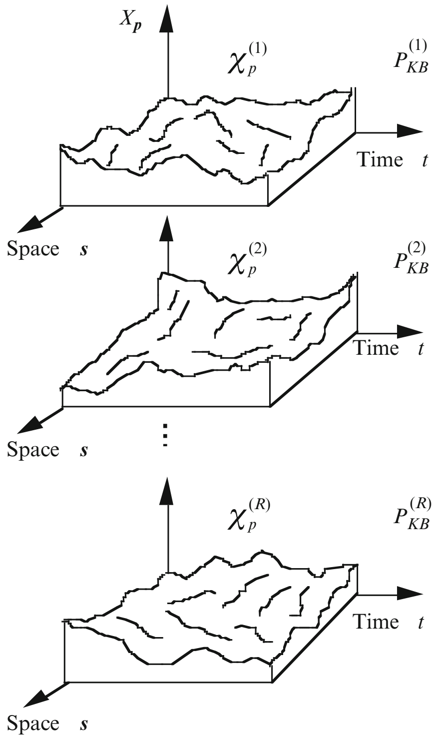


Fig. 7.1 A representation of the S/TRF model in terms of its possible realizations

(chance) – which is a fundamental idea of stochastic reasoning – is represented by the co-occurrence of the sample (horizontal) and multi-realization (vertical) perspectives in Fig. 7.1. Each particular attribute realization exhibits a certain space–time structure, whereas at each point $\boldsymbol{p}$ there could be assigned multiple attribute values, thus generating a series of realizations $\chi_{\boldsymbol{p}}^{(i)}$ with different probabilities $P_{KB}^{(i)}$ $(i = 1, \ldots, R)$ in general. Structural correlations of the S/TRF $X_{\boldsymbol{p}}$ (expressed by space–time dependence functions) have physical reality, whereas that which they correlate (i.e., the $X_{\boldsymbol{p}}$ realizations) may have not.

By studying all possible realizations of an S/TRF with the associated probabilities the investigator confronts uncertainty about a real-world situation and, at the same time, attempts to learn from the future before it happens, so to speak. The notion of multiple S/TRF realizations has its origin in the Epicurean idea of the plurality of worlds (Section 5.3.1). While each Epicurean world ought to agree with appearances, the random field realizations in Fig. 7.1 are constrained by physical knowledge and logic considerations. Indeed, from a scientific standpoint the notion that "everything is possible" in itself does not have much explanatory power: By considering any number of realizations (parallel worlds), one may be able to account for anything (including what is extremely unlikely to be the case, irrational, or even ludicrous), but say very little about "why" and "how." The logical and physical constraints imposed on the random field worlds would be certainly valuable as self-assessment tools, especially in disciplines in which "convenient" worlds are invented with no regard for truth. According to Anne Barbeau Gardiner (2007), e.g., when feminist medieval historians realized that their agenda was not served by the fact that there were only 15 known lesbians in the entire medieval millennium, the so-called lesbian-like world (realization) was invented (Bennett 2006), which arbitrarily included all the women whose lives might have offered opportunities for same-sex love (including nuns, single women, and widows). Welcome to the fantasy that passes for "truth," where historical events are misinterpreted, nonexisting "facts" are invented, logic is defeated, and rational thinking is violated.

7.3.1.2 A Linguistic Analogy

One of the attractive features of interdisciplinarity is that it offers to the investigator the opportunity to create intriguing and fruitful analogies between concepts in different disciplines. Below, an interesting analogy is made between the random field model and the binary model of structuralism that was chiefly founded in the early twentieth century by the linguistician Ferdinand de Saussure. According to this model, language is a sign system that functions in terms of a binary operational code. For each sentence, one code aspect (syntagmatic contiguity) operates along it and refers to the structural relationship between the elements of the sentence (corresponding to the structural random field aspect); and another code aspect (paradigmatic substitution) operates across the sentence and refers to relationships between each element of the sentence and other elements that are syntactically interchangeable (corresponding to the chance aspect of the random field).

The analogy between the binary linguistic and random field models may be represented as follows:

Binary linguistic model		*Random field model*
Syntagmatic contiguity	$\leftrightarrow$	Structural aspect
Paradigmatic substitution	$\leftrightarrow$	Chance aspect

For illustration purposes, consider Table 7.4. Reading the sentence "He opens the door" (realization $R1$) detects a certain relationship between its elements "he," "opens," and "door," which reveals a certain meaning of the sentence. One can also look across the sentence by substituting each of its elements with other relevant elements, thus generating several possibilities: "He opens door" ($R1$), "He closes window" ($R2$), etc. *Mutatis mutandis*, the possibilities $R1$, $R2$, etc. of the binary linguistic model can be viewed in the light of a random field model with realizations $R1$, $R2$, etc. Accordingly, the syntagmatic contiguity of the binary model may resemble the structural aspect of the random field model (as a state of being); and its paradigmatic substitution may resemble the chance element of the random field (as expressed by the realization plurality).

Table 7.4 A representation of the binary linguistic model

He opens door	$R1$
He closes window	$R2$
She shuts door	$R3$
⋮	

paragidmatic substiction (↓)

Syntagmatic contiguity (→)

7.3.2 Knowledge Is About Connecting Minds, Not Merely About Collecting Data

According to the classification postulate (CP, Section 3.5.2) the knowledge available to an agent is distinguished as being either a core (G) or a specificatory (S) KB. The KBs can be expressed in the form of mathematical operators that are suitable for quantitative analysis. Let us denote them the Ω_G and Ω_S operators so that

$$\left.\begin{aligned} G &\rightarrow \Omega_G[X_{\boldsymbol{p}}] \\ S &\rightarrow \Omega_S[X_{\boldsymbol{p}}] \end{aligned}\right\}, \tag{7.12}$$

where the formulations of Ω_G and Ω_S vary considerably, depending on the problem, the KB, and the thinking styles of the investigators involved in the IPS process (Christakos 2000).

7.3.2.1 Translating Knowledge into Operators

The level of sophistication of the methods that translate G-KB into comprehensive Ω_G operators depends on the complexity of the core KB. A method may translate the given G-KB into a set of integrodifferential equations in terms of f_G. Another G-KB may be translated into a set of simpler algebraic equations. Similarly, several techniques (encoding, probablification, and fuzzification) are used to express S-KB into useful Ω_S forms. In the case of accurate measurements, the S-form is a function of the exact database. Uncertain S-KBs are available in various soft data forms (interval data, probability functions, fuzzy sets, etc.). Translation of the datasets by means of the Ω_S-operator will not change their intrinsic value. If the datasets were of high quality in the beginning, they will continue to be the same after the translation. And if they were "random gossips of mothers-in-law" in the beginning, they will remain so after the translation.

In previous chapters we reviewed several multidisciplinary KBs (from sciences, history, public administration, art, and religion), and their quantitative representations. Below we consider a few examples of the corresponding Ω_G and Ω_S. For more examples and in situ case studies, the interested readers can consult the relevant literature. Table 7.5 (Kolovos et al. 2002) shows the Ω_G equations for a G-KB that includes the advection-reaction law of river contamination ($X_{\boldsymbol{p}}$ denotes contaminant concentration at each space–time point $\boldsymbol{p}$, a_1 is the flow velocity, and a_2 is the reaction rate constant). Table 7.6 (Christakos et al. 2005) lists the Ω_G equations linked to a G-KB that includes the modified Kermack–McKendrick law of communicable disease. The $X_{\boldsymbol{p}}$, $Y_{\boldsymbol{p}}$, and $Z_{\boldsymbol{p}}$ denote the proportions of susceptible, infected, and resistant (immune) individuals, respectively; $\eta_{\boldsymbol{p}}$ is a weighted function of the number of infected within the contact radius of a susceptible individual; λ is the rate at which infected individuals recover and become immune; β is the rate at which susceptible individuals become infected; and f_G is the PDF model associated with the G-KB.

Table 7.5 Ω_G equations of an advection-reaction contaminant law along a river

$\int\int d\chi_{\boldsymbol{p}_i}\, d\chi_{\boldsymbol{p}_j}\, \chi_{\boldsymbol{p}_i}\left(\frac{\partial}{\partial t} + a_1\frac{\partial}{\partial s_i} + a_2\right)f_G = 0$
$\int\int d\chi_{\boldsymbol{p}_i}\, d\chi_{\boldsymbol{p}_j}\, \chi^2_{\boldsymbol{p}_i}\left(\frac{\partial}{\partial t} + a_1\frac{\partial}{\partial s_i} + 2a_2\right)f_G = 0$
$\int\int d\chi_{\boldsymbol{p}_i}\, d\chi_{\boldsymbol{p}_j}\, \chi_{\boldsymbol{p}_i}\, \chi_{\boldsymbol{p}_j}\left(\frac{\partial}{\partial t} + a_1\frac{\partial}{\partial s_i} + a_2\right)f_G = 0$
$\vdots$

Table 7.6 Ω_G equations of the modified space–time Kermack–McKendrick law of communicable disease

$\int\int\int d\chi_{\mathbf{p}_i}\, d\psi_{\mathbf{p}_i}\, d\zeta_{\mathbf{p}_i}\, \chi_{\mathbf{p}_i}\left(\frac{\partial}{\partial t}+\beta\eta_i\right)f_G=0$
$\int\int\int d\chi_{\mathbf{p}_i}\, d\psi_{\mathbf{p}_i}\, d\zeta_{\mathbf{p}_i}\left[\psi_{\mathbf{p}_i}\left(\frac{\partial}{\partial t}+\lambda\right)-\beta\,\eta_i\,\chi_{\mathbf{p}_i}\right]f_G=0$
$\int\int\int d\chi_{\mathbf{p}_i}\, d\psi_{\mathbf{p}_i}\, d\zeta_{\mathbf{p}_i}\left(\zeta_{\mathbf{p}_i}\frac{\partial}{\partial t}-\lambda\,\psi_{\mathbf{p}_i}\right)f_G=0$
$\vdots$

Table 7.7 Ω_S forms of soft attribute data

$\chi_{\mathbf{p}_i}\in I$	$P_S[w(\chi_{\mathbf{p}_i})]$
$f_S(\chi_{\mathbf{p}_i})$	$P_S[w(\chi_{\mathbf{p}_i},\ \chi_{\mathbf{p}_j})]$

The probabilistic representation of *S*-KB is necessary because in situ evidence often introduces a number of technical and anthropocentric elements into the consideration of the *S*-KB, including limitations of the observation (measuring) devices, and even of the experimenters (observers) themselves. Table 7.7 includes a few Ω_S examples linked to uncertain data, where *I* is an interval of possible attribute values, f_S is a site-specific PDF, P_S denotes probability, and *w* is an empirical function relating attribute values between pairs of space–time points.

For numerical illustration, Fig. 7.2 displays in situ examples of soft data in terms of triangular (generally nonsymmetric) f_S of radioactive ^{137}Cs soil contamination (in Ci Km^{-2}) in the western part of the Bryansk region (Russia) due to the Chernobyl nuclear accident (Savelieva et al. 2005). Other examples of *S*-KB include remote sensing and satellite-based data, simulations, and geographical surveys. Techniques have been developed for assimilating *S*-KB in the form of fuzzy datasets (Kovitz and Christakos 2004a). In retrospection, one may find it difficult to distinguish what is often a thin line between hard (objectively accurate) and soft (uncertain) data. What is a hard datum for one experimentalist may be soft information for another, but this possibility should not discourage one's modeling efforts. To this end criteria based on sound reasoning and good science can help in making a good decision. The decision process would situate itself at the confluence of the different data interpretations, and thus wed epistemic and ontic perspectives by questioning them in an active, continuous, reflective, and if necessary, radical manner.

7.3.2.2 Knowledge Operators for Multidisciplinary Problems

The situation may be more complicated when an investigator is dealing with a multidisciplinary problem. In such cases one must have the ability to integrate diverse KBs and the underlying thinking styles from a variety of disciplines, all relevant to the problem at hand, to cross over into new conceptual domains and

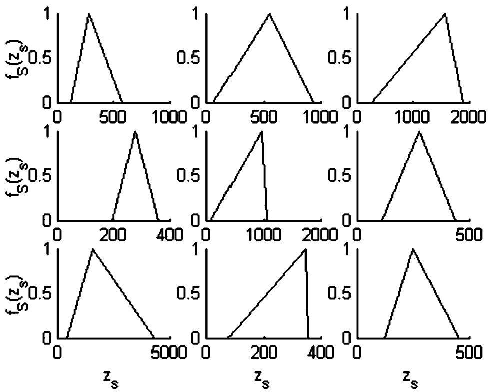


Fig. 7.2 Soft ^{137}Cs data (Bryansk, Russia)

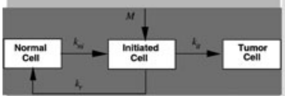
S-T Dependence Models of Arsenic Concentration	$\overline{E}(\boldsymbol{p}),\ \ c_E(\boldsymbol{p},\boldsymbol{p}')$
Exposure-Response (Linear/Empirical)	$H(\boldsymbol{p}) = P_B + k\ E(\boldsymbol{p})$
Exposure-Response (Nonlinear/Mechanistic) 	$H(\boldsymbol{p}) = N_t(t = life\ expectancy)$ $\frac{dN_n(t)}{dt} = -k_{ni}\,N_n(t) + [0.015 - 7\cdot 10^{-4}E(\boldsymbol{p})^{0.3}]N_i(t)$ $\frac{dN_i(t)}{dt} = k_{ni}\,N_n(t) - [0.015 - 7\cdot 10^{-4}E(\boldsymbol{p})^{0.3}]N_i(t) - k_{it}N_i(t) + M\,N_i(t)$ $\frac{dN_t(t)}{dt} = k_{it}\,N_i(t)$
Response-Population Damage	$\Psi(\boldsymbol{p}) = \theta(\boldsymbol{p})[H_B + H_{As}(\boldsymbol{p})]$

Fig. 7.3 *G*-KB considered in the study of population bladder cancer mortality due to exposure to Arsenic in drinking water (Bangladesh)

utilize their intelligence. In situ IPS is primarily about connecting energetic minds (worldviews, argumentation modes, and cultures), not merely collecting dry and lifeless data. In a multidisciplinary setting, the expert of each discipline is an interpreting and interpreted being at the same time. For illustration, Fig. 7.3 summarizes the interdisciplinary *G*-KB considered in the Bangladesh human exposure study, including space–time models of arsenic distribution in groundwater, exposure-response laws (empirical and mechanistic/carcinogenetic), and response-population damage (bladder cancer) dynamics (for a detailed discussion of these KBs, notation, terminology and techniques, see Serre et al. 2003). Figure 1.2 provided a visual representation of some of the KBs used in the Black Death epidemic in fourteenth-century Europe (Christakos et al. 2005). It is possible that the data contained in the KBs can be further analyzed to produce new information or to test existing hypotheses. In the study of the Black Death epidemic, the assimilation and processing of diverse KBs (complex arguments found in chronicles, accounts, reports, letters, testaments, etc.) was part of a systematic effort that involved a group of experts from different disciplines,[14] and exhibited a number of noticeable characteristics, such as: (i) The synthesis of surviving evidence, sharp insight, and shrewd arguments made by historians, chroniclers, and clergymen, among others.[15] (ii) The use of techniques of logic generated new and valuable data. In the city of Lübeck (Germany), e.g., given its population and the death rates of the subpopulations of property owners, city clerks, and city councilors, it was inferred (with a reasonably high probability) that the overall population death rate due to Black Death was roughly 1 in 3. (iii) Implementation of knowledge consistency rules made it possible to eliminate conflicting KB elements; see, e.g., the case of the cities of Florence and Bologna (Italy) discussed in Section 3.6.4. Moreover, Fig. 3.1a showed that in the neural tube defects study (Heshun county, China) the available knowledge included social strata relevant to the problem, in addition to the physical and biological KBs. Special attention is required when integrating social KBs into the IPS process, since, unlike physical systems, a social system is composed of thinking investigators, in which case the effort of an investigator–observer to study a social system may be complicated by the fact that many other investigators-observers are trying to do the same thing. The specifics of the situation make it necessary to create some kind of dialectic between the social system and the investigator's chosen approach (ideas, techniques, and ultimate presumptions) toward the solution of the problem. This dialectic is a sort of *ad augusta per angusta*,[16] not an easy thing to do but a necessary thing, nevertheless.

Last but not least, the persisting methodological problems of mainstream health statistics and corporate geostatistics (Section 9.4) provide a strong motivation for the distinction between core and site-specific KBs. Unlike Kriging (statistical regression), in which an internal conflict is caused by the fact that both the generalization and justification stages are based on the same dataset, in the Epibraimatics formulation the two stages rely on distinct KBs, the $G-$KB and the S–KB,

[14] Coryphaeus among them was Dr. Ricardo A. Olea, a man who belongs to the quickly vanishing breed of the gentleman-scholar.

[15] One wonders what the postmodern approach would be concerning the Black Death study, which cannot but rely almost exclusively on historical sources. Given its ahistoric perspective, the postmodern world seems to have turned into sort of a Black Hole.

[16] Getting to high places by narrow roads.

respectively. This formulation is at the same time normative, explanatory, reflective, and practical.

7.3.3 *Teleologic Operator: The Machine and the Artist*

One of the metaphors examined in Chapter 3 was that the brain may be seen as a *machine* operating in terms of a "cause–effect" scheme, whereas the mind as an *artist* trying to realize an metaphor. Let us explore this metaphor a little further.

7.3.3.1 Information Seeking

Rémy de Gourmont once claimed that, "To know what everybody else knows is to know nothing." In the teleology of reason context, this desideratum could be interpreted as seeking the model that generates as much new knowledge as possible. As emphasized in Section 3.5.3, information seeking is a basic mental function. As a matter of fact, the requirement to deliver large amounts of information with short-time delays is considered an important reason for the brain's location close to the agent's eyes and nose (Freeman 2000). Surely, information seeking can explain a wide range of logical reasoning tasks based on certain assumptions about the statistical structure of the real-world, and the relative values of different information types (Workman and Reader 2004). In coordination with the above brain activity, the TP (Section 3.5.3) suggested that a prime task of the mind is to seek a probability model, say f_G (or P_G),[17] describing the uncertainty about an attribute $X_{\boldsymbol{p}}$ in a way that provides maximum information I_G to the investigator given the G-KB available. The insight behind the above suggestion is that, the more vague and general a probability model is, the more alternatives (attribute realizations) it includes (hence, it is a more probable model) and, at the same time, the less informative it is (see the inverse relation between probability and information in Section 7.2 above). The example in Section 7.2.5 considered two possible models $f^{(1)}_{G,\boldsymbol{p}}$ and $f^{(2)}_{G,\boldsymbol{p}}$ of an attribute, where $f^{(2)}_{G,\boldsymbol{p}}$ allows more attribute realizations than does the $f^{(1)}_{G,\boldsymbol{p}}$, i.e. $R^{(1)} < R^{(2)}$. Therefore, it is more likely that one of the $f^{(2)}_{G,\boldsymbol{p}}$ realizations will occur than one of the $f^{(1)}_{G,\boldsymbol{p}}$ realizations; and the $f^{(2)}_{G,\boldsymbol{p}}$ is a less informative model than $f^{(1)}_{G,\boldsymbol{p}}$. To this effect, one cannot avoid the literary metaphor that the statement "Que será será" (whatever will be, will be) is an example of an absolutely safe model (allows all possibilities), but it actually provides no information at all.

[17] For mathematical convenience, it is often preferable to work in terms of the PDF f_G.

7.3.3.2 Formalization and Its Merits

As we saw in Section 7.2, there are good reasons to express the information in a space–time setting as inversely proportional to the corresponding attribute probability. Mind's perspective cognition is expressed operationally in terms of the maximization of a suitable informational functional with respect to the probability model and subject to the *G*-KB. This functional essentially represents the TP in a space–time domain. Due to uncertainty, a reasonable expression of the functional is in terms of the expected information $\overline{I_G}$, thus leading to the *teleologic operator*

$$\left.\begin{array}{ll} \max_{f_G} & \overline{I_G} \\ \text{s.t.} & \Omega_G \end{array}\right\} \rightarrow f_G, \tag{7.13}$$

where Ω_G is the set of *G*-equations discussed in Section 7.3.2 above. The *G*-KB of the TP operator (7.13) may be multisourced, multidisciplinary, multithematic, and uncertain to a varying degree, depending on the in situ situation and the investigator's cognitive condition. Equation (7.13) may be then seen as a rationalization of the mental state of intentionality involved in TP.

As noted earlier, a concise definition of $\overline{I_G}$ is in terms of the B–S entropy, $\overline{I_G} = \varepsilon^{B-S}_{G,\boldsymbol{p}}$. Among the scholars who studied in depth B–S entropy maximization was Edwin T. Jaynes (1983, 2003). Jaynes was most responsible for the popularization of the idea in physical sciences. His very significant contribution was greatly unrecognized during his lifetime, which is probably the reason that he once stated: "Every new conceptual idea ... must go through a phase of facing opposition from two sides: the entrenched Establishment who thinks that its toes are being stepped on, and a lunatic fringe that springs up, seemingly by spontaneous generation, out of the idea itself ... the lunatic fringe has no vested interest in anything because it is composed of those who have never made any useful contribution to any field. Instead, they are parasites feeding on the new idea; while giving the appearance of opposing it, in fact they are deriving their sole sustenance from it, since they have no other agenda" (Jaynes 1991: 2). The reader may have noticed that the behavior of what Jaynes calls the "lunatic fringe" brings to mind the "Para-Oedipal act" discussed in Section 1.8.4.

There are four items concerning the TP operator (7.13) that are worth bringing to the readers' attention: (a) Eq. (7.13) acknowledges the merit of core KBs in deriving a meaningful model f_G, and provides a quantitative formulation of the genetically endowed brain potential for producing an informative problem–solution given appropriate inputs. (b) Eq. (7.13) follows the fertile line of thought that the more information a solution contains, the greater the number of ways by which it might be proven false. This implies that if a problem–solution is at risk of being proved false, it has a higher information content; and the more prone a solution is to being proved false, the more testable it is. In other words, information content is in inverse proportion to probability and in direct proportion to testability.

(c) Eq. (7.13) relates to the strategy that the more uncertain one is about a possibility (e.g., problem–solution, prediction of a future event or human venture), the higher the payoff will be if the possibility turns out to be actuality. Several examples of this strategy in society, politics, and business are outlined in the literature (Taleb 2008a: xix–xx).[18] (d) Eq. (7.13) hypothesizes that maximizing the expected information also maximizes the fitness of the problem–solution, in the sense introduced by the TP. On the average the information will be fit, in which case Eq. (7.13) generates a solution f_G with the maximum average fit. The readers should keep in mind that the four items above also provide useful "checkpoints" for knowledge reliability purposes.

7.3.3.3 The Case of Myopic Vision

The B–S entropic formalization of Eq. (7.13) is just one possible way to define $\overline{I_G}$. Epibraimatics theory surely does not need to restrict itself to the B–S entropy. Rather the methodological framework outlined in this section remains valid if a different definition of $\varepsilon_{G,\boldsymbol{p}}$ is used (see, Table 7.3). The choice of $\varepsilon_{G,\boldsymbol{p}}$ would depend on the thinking mode we employ, and the in situ conditions of the problem to be solved, among other things.

Furthermore, the conceptual range of TP is very wide and extends beyond the information-theoretic framework. This means that if mind's intentionality state was to be expressed in non-informational terms, the I_G would have to be replaced with a different kind of a mathematical operator. In sum, a central requirement of Epibraimatics is to avoid at any cost the *myopic vision* phenomenon, according to which a meaningful IPS formulation can be found in a single way. This requirement involves a willingness on behalf of the investigator to examine issues of axiological meaning, intellectual purpose, and moral justification about one's beliefs and actions; and their association with the basic IPS postulates of Section 3.5.

7.3.3.4 A Three-Place Relation

The space–time meaning of the entity $\overline{I_G}$ in Eq. (7.13) has been considered in the context of analysis and modeling of natural systems and their attributes (Christakos 2000: 124). According to this interpretation, Eq. (7.13) recognizes the decisive role that the investigator plays in determining the nature of IPS. In this respect, the meaning of a solution is not regarded as involving a two-place relation between theory and evidence, but rather a *three-place relation* between theory, evidence, and the investigator.

In a certain philosophical context, the investigator's role is twofold: (a) in the spirit of Heidegger's (1996) description of humans as *dasein* (being there) and not only as objects (investigators projecting their purposes onto items in the world and,

[18] In Taleb's terminology, this strategy follows what he calls the "Black swan logic."

hence, making them what they are); and (b) in line with the *uncertainty principle* concerning an observer–investigator's role in determining what an object does at any given moment (i.e., at every moment the rational observer decides what one can determine about the world[19]; Hughes 1992). Last but not least, some interdisciplinarians among the book's readers may consider a conceptual comparison between the maximization perspective of Eq. (7.13) and Merleau-Ponty's process of hypothesis testing that seeks to achieve maximum grip through an intentional arc (Merleau-Ponty 1962). The intentional arc refers to the tight connection between the investigator and the real-world. The investigator is set to respond to changing conditions of the world and adopt accordingly. Surely, the investigator considers these conditions from a certain perspective (or within the confines of a certain paradigm), and decides that they afford specific actions. The kind of affordances to be considered would also depend on past experience concerning similar situations. The intentional arc assumes that all past experience is projected back into the world, in which case the best representation of the world is the world itself.

7.3.4 Adaptation Operator: The Critical Roles of Content and Consistency

From an evolutionary perspective, adaptations involve reasoning mechanisms of the agent's brain that respond to the changing conditions of the physical world. In this setting, adaptation rules may be seen as instructions how to organize, revise, or update the problem–solution relative to the emerging site-specific features. In the IPS milieu, hence, adaptation may take novel forms in an effort to avoid the situation vividly described by Thomas Kuhn (1962) in which people cling to outdated opinions with the same desperation that survivors of the Titanic must have clung to their lifeboats (which means, *inter alia*, that an investigator should not limit oneself to the statistical conditional as the only possibility of probability updating in the light of new data; Sections 6.2 and 6.3).

7.3.4.1 Adaptation Types

Methodologically, two main types of adaptation to the changing in situ conditions are usually considered: *Revision*, in which both the *G*-KP and *S*-KB refer to the same in situ situation; and *updating*, in which the *S*-KB is about the present in situ situation, whereas the *G*-KB refers to the past.[20] In the case of a physical attribute

[19] The observer, e.g., cannot know with complete accuracy a particle's position and velocity at the same time – the observer has to choose one or the other.

[20] In Bayesian studies the term "updating" is often used to denote the availability of new data about the same old system (in which case the term "revision" might be more appropriate), whereas in the present section the term "updating" refers to data about the new state of a changing system.

varying across space–time, and due to considerable uncertainty (associated with incomplete knowledge, natural attribute heterogeneity, and complex underlying mechanisms), it is more meaningful for operational purposes to present an agent's thoughts concerning the unknown attribute states in terms of probability models assigned to each space–time point of the domain between several points. Hence, according to the AP (Section 3.5.4), the presence and special structure of the *S*-KB suggest that an additional operational rule is needed to adapt the model f_G obtained by the TP operator (7.13). Accordingly, the AP operator should account for the investigator's understanding of the specifics of the in situ problem. More specifically, in the case that the *S*-KB differs in some space–time domains from the *G*-KB, the agent needs to decide the form and the extent the adaptation should take, i.e., what relative weights should adaptation give to different knowledge sources when deriving a problem–solution. This situation reveals a basic conceptual element that the present approach and Piaget's learning process (Section 3.4.4) may have in common: if a new experience does not fit with the current problem–solution, the latter may also need to be adapted to a lesser or larger extent.

7.3.4.2 Adaptation Context

In short, the way an investigator perceives a particular problem and assigns to it an adequate adaptation rule generally depends on the real-world setting in which the problem is presented. The way language is used in a problem formulation may affect the choice of the adaptation rule, as well. In fact, the rigorous implementation of formal logic in problem–solution may involve an exhaustive analysis of language usage and word meaning in order to avoid self-contradictory and meaningless statements. It is not unusual that an investigator uses language in problem description and analysis in ways that often make it difficult for other people to understand the investigator's thoughts, intentions, interpretations, and experiences. There is then an important set of assumptions that is often left out of the problem–solution, in which case, others are tempted to fill in the blanks with their own set of assumptions. Typical causes of confusion include vague use of words (which do not clearly denote solution elements that people can agree on), assumed causal connections (which, in reality, are merely statistical associations), quantitative approximations (which are not universally accepted), and imposed limits (which exclude certain options or possibilities).

Some examples can demonstrate the importance of the context within which general adaptation operates. Two satellites, Sat_I and Sat_{II} orbit around the Moon and are programmed to land while transmitting their status to the agent on Earth. Let X_i indicate that the Sat_i ($i = I,\ II$) is still in orbit. At time t the agent receives a signal from one of the satellites that is still in orbit but, due to interference, it is not possible to identify which satellite it is. Hence, the *G*-KB of the agent at time t is logically represented as $X_I \vee X_{II}$ (either Sat_I or Sat_{II} is still in orbit). At time $t' > t$, the agent receives a signal that Sat_I has landed on Moon, which is the agent's *S*-KB represented as $\neg X_I$ (Sat_I is not in orbit, since it has landed). In this case, the final K-KB is denoted by $\neg X_I$, i.e.,

$$\left.\begin{array}{r} G : X_I \vee X_{II} \\ S : \neg X_I \end{array}\right\} \Rightarrow K : \neg X_I. \tag{7.14}$$

In other words, the Sat_I has landed and, hence, it is not in orbit (since the G-KB that one of the satellites had not landed at time t was possibly coming from Sat_I, the status of the Sat_{II} is unknown). As another example, consider two theaters, Th_I and Th_{II}, in one of which a play is to be performed. Let X_i indicate that the play will be performed in Th_i ($i = I,\ II$). The G-KB of an agent is logically represented as $X_I \vee X_{II}$ (the play will be performed either in Th_I or in Th_{II}). Subsequently, the S-KB is that the play will not be performed at Th_I, which is denoted as $\neg X_I$. In this case, the K-KB is represented by $\neg X_I \wedge X_{II}$ (the play will be performed at Th_{II} but not Th_I), i.e.,

$$\left.\begin{array}{r} G : X_I \vee X_{II} \\ S : \neg X_I \end{array}\right\} \Rightarrow K : \neg X_I \wedge X_{II}. \tag{7.15}$$

Comparison of Eqs. (7.14) and (7.15) shows that, depending on the adaptation context, G- and S-KBs of the same forms can lead to different K-KBs. Notice that the adaptation context of (7.14) is that of updating, whereas the adaptation context of (7.15) is that of revising.

7.3.4.3 The Role of Consistency

Another issue of great significance is the *consistency* of the different KB elements that are considered in the quantitative AP representation. As Section 3.6.4 elaborated, there are several reasons why elements of the G-KB may be inconsistent with those of the S-KB. Accordingly, the AP operator needs to insert the S-KB into the model f_G (previously constructed on the basis of G-KB) without generating any inconsistency; i.e., the union operator in $K = G \cup S$ must be applied in a way that averts inconsistencies between elements of the G- and S-KBs. This is not a trivial matter, since the AP often involves the combination of KBs that are structured in complex ways.

The readers may have noticed that the analysis above requires a twofold decision on behalf of the investigator: (a) which of the mutually inconsistent KB elements should be included in the final K-KB and which should be abandoned; and (b) when there exist more than one AP operators that can restore consistency in Item (a), which one should an investigator use. Clearly, this twofold decision is a matter of expert judgment, scientific insight, inwardness, well-roundedness, and sound interpenetration, rather than just a matter of abstract rationality or pure logic (e.g., logic may dictate that some KB elements have to be eliminated in order to maintain consistency, but logic alone usually cannot specify which exactly these elements should be).

7.3.4.4 Conditionals of Reasoned Facts and Mark Twain's Cat

Building on the analysis in the sections above, I argue that the reasoning mechanism of adaptation may take various forms: physical, logical, and statistical forms. Each one of these forms has its own merits in the twofold context of consistency resolution described above. In particular, *physical* adaptation is associated with a causal connection between S and $X_{\boldsymbol{p}_k}$ by means of a physical law; *logical* adaptation, so that S logically implies $X_{\boldsymbol{p}_k}$, while issues concerning S and $X_{\boldsymbol{p}_k}$ are not necessarily beholden by physical laws; and *statistical* adaptation, so that the occurrence of S offers statistical evidence for that of $X_{\boldsymbol{p}_k}$, without necessarily involving physical or logical connections.

Adaptation leads to an updated model f_K of f_G that additionally accounts for the S-KB while it maintains the internal consistency of the scientific process. In Epibraimatics there are various proposals concerning the mathematical expression of the model f_K. The *adaptation operator* can be generally expressed as

$$\left.\begin{array}{r}\max\limits_{f_K}\Psi_K\\ \text{s.t.}f_G,\;\;\Omega_S\end{array}\right\}\rightarrow f_K, \tag{7.16}$$

where Ψ_K measures adaptation taking into account the content and context of the problem, and Ω_S denotes the set of S-based equations. Otherwise stated, f_K is the model that updates f_G in light of changes in the investigator's cognitive condition, and the problem's in situ state. Equation (7.16) may be seen as a rationalization of the mental function of fitness involved in AP. The AP operator (7.16) seeks a model f_K that allows a maximally meaningful adaptation of f_G given Ω_S, whereas the process leading to f_K contains both quantitative and qualitative elements. There are several ways to choose an adequate Ψ_K that it takes into account the in situ features of the particular problem, the epistemic condition of the investigator, and the relation between the two. We saw earlier, Eqs. (7.14) and (7.15), that depending on the adaptation context, the G- and S-KBs of the same forms can lead to different K-KBs and, accordingly different PDF. In light of the discussion in Section 6.2, one could interpret Ψ_K in terms of the substantive conditional $(\cdot\backslash\cdot)$, i.e. $f_K(\chi_{\boldsymbol{p}_k}) = f_G(\chi_{\boldsymbol{p}_k}\backslash S)$. The $\cdot\backslash\cdot$ accounts for space–time attribute dependencies, the agent's goals and epistemic condition, and the relative importance of G- and S-KBs. Based on the analysis in previous chapters, some illustrative types of conditionals are shown in Table 7.8. In the case that the contextual and cognitive conditions of a problem suggest the choice of an SC probability, i.e. $\cdot\backslash\cdot\;\equiv\;\cdot|\cdot$, in which case Eq. (7.16) yields (7.17a). If an MC probability seems more appropriate, then Eq. (7.16) leads to (7.17b), whereas if an EC probability is chosen, then one gets Eq. (7.17c). Assume, e.g., that the PDF f_K that maximizes the adaptation measure Ψ_K is the SC (7.17a), and the S-KB consist of a set of hard data $X_h:\;\;X_h=\chi_h$ and a set of soft data $X_s:P_s[\chi_s\in I_S]$, I_S is an interval of values. If $f_G(\chi_h,\chi_s,\chi_k)$ is the PDF obtained in Eq. (7.13), Eq. (7.16) yields $f_K^{sc}(\chi_{\boldsymbol{p}_k})\propto\int_{I_S}d\zeta_s f_S(\zeta_s)f_G(\chi_h,\zeta_s,\chi_{\boldsymbol{p}_k})$ (see, also, Table 7.9 below). As another example, by using physical theory the probability

Table 7.8 Types of conditionals

Statistical conditional (SC)	$f_K^{sc}\left(\chi_{\boldsymbol{p}_k}\right) = f_G\left(\chi_{\boldsymbol{p}_k}\|S\right)$ (7.17a)
Material conditional (MC)	$f_K^{mc}\left(\chi_{\boldsymbol{p}_k}\right) = f_G\left(S \rightarrow \chi_{\boldsymbol{p}_k}\right)$ (7.17b)
Equivalent conditional (EC)	$f_K^{ec}\left(\chi_{\boldsymbol{p}_k}\right) = f_G\left(S \leftrightarrow \chi_{\boldsymbol{p}_k}\right)$ (7.17c)

Table 7.9 Types of conditionals

S-KB: $X_d = X_h \cup X_s$	$P_K^{sc}\left[X_{\boldsymbol{p}_k} \leqslant \chi_{\boldsymbol{p}_k}\right] = P_G\left[\left(X_{\boldsymbol{p}_k} \leqslant \chi_{\boldsymbol{p}_k}\right)\|S\right]$
$X_d : \begin{cases} X_h = \chi_h \\ P_S[X_s = \chi_s \in I_S] \end{cases}$	$A^{-1}\int_{-\infty}^{\chi_{\boldsymbol{p}_k}} d\xi_k \int_{I_S} d\zeta_s f_S(\zeta_s) f_G(\chi_h, \zeta_s, \xi_k)$ where $A = \int_{I_S} d\zeta_s f_S(\zeta_s) f_G(\chi_h, \zeta_s)$
$X_d : \begin{cases} X_h = \chi_h \\ P_S\left[X_s = \chi_s \in I_s \wedge X_{\boldsymbol{p}_k} = \chi_{\boldsymbol{p}_k} \in I_k\right] \end{cases}$	$A^{-1}\int_{-\infty}^{\chi_{\boldsymbol{p}_k}} d\xi_k \int_{I_S} d\zeta_s f_S(\zeta_s) f_G(\chi_h, \zeta_s, \xi_k)$ where $A = \int_{I_S} d\zeta_s \int_{I_K} d\zeta_k f_S(\zeta_s, \zeta_k) f_G(\chi_h, \zeta_s, \zeta_k)$

that an atom in state $\chi_{\boldsymbol{p}_i}$ will radiate a photon and drop to state $\chi_{\boldsymbol{p}_k}$ is found to be $P_G^{mc}(\chi_{\boldsymbol{p}_i} \rightarrow \chi_{\boldsymbol{p}_k}) = |\sum_{q=1}^{\infty} B_q(\chi_{\boldsymbol{p}_i}, \chi_{\boldsymbol{p}_k}) e^q|^2$, where $B_q(\chi_{\boldsymbol{p}_i}, \chi_{\boldsymbol{p}_k})$ are functions of the two states, and e denotes the fundamental charge of the electron.

As the above analysis signifies, several factors play an essential role in the choice of Ψ_K. Some experts maintain that under certain conditions Eq. (7.17a) tends to assign more weight to the S-KB over the G-KB (see, also, the advection-reaction case in Fig. 7.4 later). When the two KBs differ, certain elements of the KBs will have to be eliminated for consistency restoration purposes. A Darwinian theory, e.g., distinguishes between two factors contributing to natural selection, factors internal to an organism (endogenous) and those external to it (exogenous), and then it attaches considerably more weight to the exogenous factor. In knowledge-theoretic terms this may imply that S-KB is more significant than G-KB, in which case Eq. (7.17a) may be considered. In other physical situations, the rules (7.17b) and (7.17c) may give epistemic priority to elements of the G-KB over those of the S-KB (e.g., these are situations in which established scientific theories describe the attribute's distribution). For a different kind of an example, assume that the study's goal is to maximize the dependence of a realization $\chi_{\boldsymbol{p}_k}$ on S (or improve attribute's predictability at $\boldsymbol{p}_k$) as measured by the CDI Φ_S in Eq. (6.3.9), i.e., $\Psi_K = \Psi_K(\Phi_S, \cdot\backslash\cdot)$. In light of Eqs. (6.45)–(6.46), in certain in situ situations the investigators would favor the conditional (7.17b) rather than (7.17a) and (7.17c), since f_K^{mc} is associated with the largest Φ_S value. A numerical illustration of the effects of these conditionals is given in Fig. 7.4. The initial model f_G was obtained using the G-KB that included an advection-reaction law of dynamic contaminant distribution along a river (the relevant equations were presented in

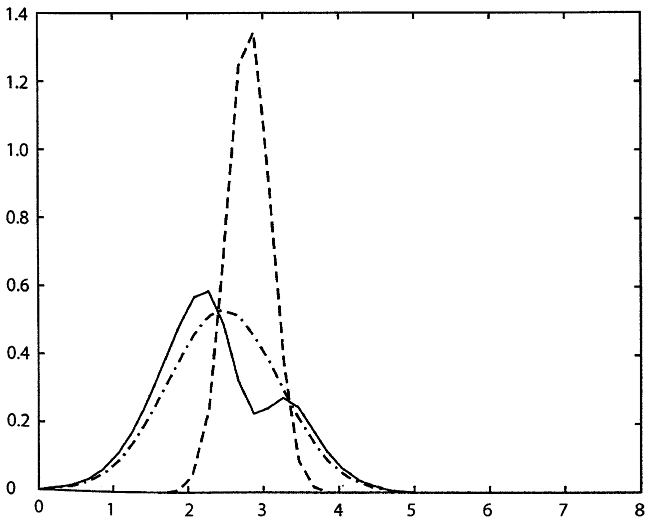


Fig. 7.4 The f_G, f_K^{sc} and f_K^{ec} are denoted by the dashed–dotted, the dashed, and the continuous lines, respectively (Christakos et al. 2002a)

Table 7.5). An element of the S-KB in the form of an interval datum at a space–time point was subsequently assimilated in Fig. 7.4. When the statistical conditional rule (7.17a) was used, the derived $f_K = f_K^{sc}$ assigned more weight to S as indicated by its vertically extended shape at the datum point; whereas, when the rule (7.17c) was used, the derived $f_K = f_K^{ec}$ assigned more weight to the physical law, as indicated by f_K^{ec}'s tendency to stay closer to the shape of f_G (but it also accounted for the site-specific evidence, as indicated by the abruptly changing shape of the PDF at the datum point). As noted earlier, laws (physical, biological, ecological, etc.) do not have the same level of fundamentality. Fred S. Roberts (1979) distinguished between "well-developed" sciences, such as physics, and "less well-developed" sciences, such as psychology or sociology. Admittedly, laws carry more weight in well-developed sciences, in which case one gives priority to G-KB.

Before leaving this section, I bring to the readers' attention that operational adaptation assimilates not merely raw facts and brute data but rather *reasoned* facts and data of the S-KB, which have been derived using procedures (experimental, observational, or computational) with sound theoretical support, clearly expressed presuppositions, and sound methodology. When faced with in situ evidence, the adequate implementation of the AP operator requires that the investigator does not focus merely on appearances (description of routine facts, processing numerical values), but also develops a capacity for correct insights (infer reality behind appearance, detect implicit information). A literary equivalent can be found in Mark Twain's sharp comment: "We should be careful to get out of an experience only the wisdom that is in it – and stop there; lest we be like the cat that sits down on a hot stove-lid. She will never sit down on a hot stove-lid again, and that is well; but also she will never sit down on a cold one anymore." Focusing solely on raw and unevaluated experience, while lacking proper attention to matters of essence, interpretation, and critical perspective would make adaptation a mere symbolic gesture, empty of meaning and substance.

7.3.5 Synergetic Action of the Operators

Be all that as it may, the TP and AP operators above act in synergy. In the IPS framework, the TP operator represents a stage of reflection and introspection, whereas the AP operator represents a stage of cross-checking and updating. An investigator is interested in how thinking about TP can stretch one's understanding about AP, and not just TP (and vice versa). From an evolutionary psychology perspective, the two operators are consistent with the investigator's innate and instinctive needs to make sense of the world using mental models, which is called *equilibrium*. New data from experience may disturb the equilibrium, which must be accommodated by updating the model and establishing a new equilibrium.

7.3.5.1 Blending TP and AP Operators

A visual illustration of the process that fuses the TP and AP operators, and leads to the final attribute representation, is given in Fig. 7.5: At the initial stage, the attribute $X_{\boldsymbol{p}}$ is represented by a set of realizations $R_G = \{\chi_{\boldsymbol{p}}^{(1)}, \ldots, \chi_{\boldsymbol{p}}^{(R)}\}$ generated by the TP operator in light of G-KB. At the following stage, a set of realizations $R_S = (\chi_{\boldsymbol{p}}^{(l_1)}, \ldots, \chi_{\boldsymbol{p}}^{(l_R)})$ emerges on the basis of S-KB. By means of an appropriate AP operator, the two previous knowledge systems yield a final set of realization $R_K = (\chi_{\boldsymbol{p}}^{(m_1)}, \ldots, \chi_{\boldsymbol{p}}^{(m_R)})$ that represents the integrated KBs, $K = G \cup S$. In order to restore consistency of any inconsistent KB elements, the AP operator offers a justified choice of realizations that need to be abandoned, and a mechanism to incorporate the remaining realizations into the IPS process. Conceptually, knowledge integration via elimination of certain realizations can be seen in the same manner that certain mathematical terms of an equation are eliminated via cancelation; the function and significance of these terms in the context of the equation is not undervalued by the act of cancelation, which rather represents a mode of their appropriate integration with the other terms of the equation.

7.3.5.2 Cognitive and Evolutionary Elements of the Operators

The TP and AP operators introduce a conceptual synthesis of different inputs to create emergent structures that result in new tools and ways of thinking in an IPS setting. Essential cognitive elements implicitly present in Eqs. (7.16)–(7.17)

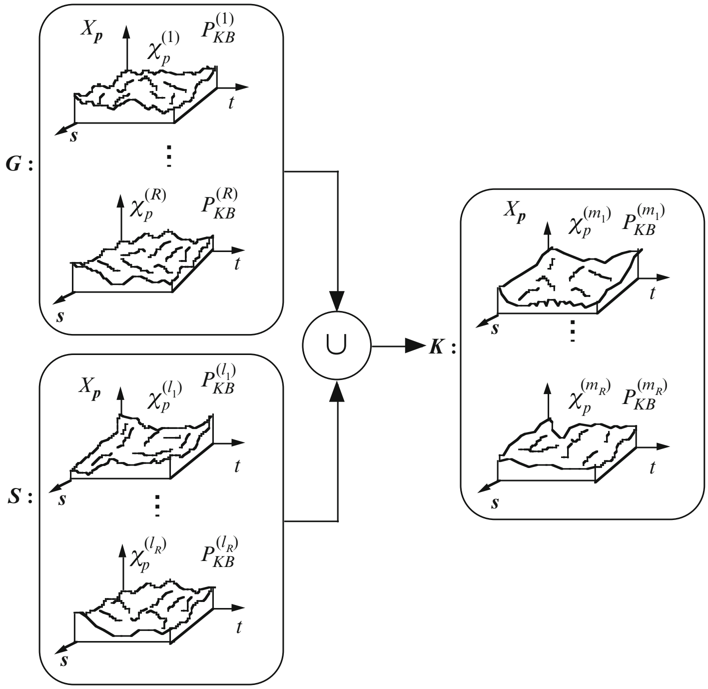


Fig. 7.5 An illustration of the process blending the teleologic and adaptation operators

include (a) *inputs* (different KBs, concepts, and techniques) about the system or attribute of interest; (b) *relations* and *links* (analogical, metaphorical, etc.) between inputs; and (c) *synthesis* (conceptual operations and critical thinking) that projects structure from Items (a) and (b) into the problem–solution. Inputs from different fields of inquiry Item a and links between the inputs Item b can be merged Item c to produce a solution showing influence of the inputs and links without being merely a "cut-and-paste" combination of Items a and b (in other words, some elements from a and b are projected into the solution, some are not, and some others are fused in the process). Therefore, the solution exhibits an emergent structure that includes relations that may not be present in the inputs, but arise through synthesis and selective projection. This solution structure, however, contradicts neither the relevant KBs (*G* and *S*) nor the agent's critical thinking mode. Item c implies that IPS involves a *holistic* process, in the sense that one often cannot specify one element of the process (e.g., a belief) without appealing or, at least, presupposing several others.

The TP and AP operators above are based on postulates with an evolutionary flavor, i.e., they possess a prescriptive character, and evolve as new core knowledge and site-specific data emerge. In a sense, the above equations provide a quantitative expression of the Chomskian hypothesis that the brain has been biologically endowed with an innate predisposition for acquiring knowledge and a potential for experience, vis., with a readiness for epistemic achievements (such as solving an important problem). Clarity, richness, and detail constitute some of the main attractions of these operators, whose main objective remains to establish a framework that integrates various core and site-specific KBs into the ultimate IPS process. The framework certainly possesses explanatory and predictive context, in addition to descriptive. The empirical *S*-KB has an immediate evidential character (in terms of observations and measurements), but it may also possess a rational component. Similarly the theoretical creations of the *G*-KB may benefit from hard evidence (e.g., a theoretical space–time dependence model may be calibrated using relevant data). This is hardly surprising, given the lack of a clear and unequivocal distinction between mind and Nature. Last but not least, there are other potentially creative IPS elements: *hidden knowledge* (i.e., a solution that provides a deeper than expected understanding of the relationship between observable entities and their underlying mathematics); and the relevant *law of unintended consequences* (i.e., a solution that opens a whole new series of unanticipated consequences).

7.4 Mathematical Space–Time Formulation of IPS

Epibraimatics allows different kinds of mathematical IPS formulations, which is one of its attractive features. Section 2.3.1.3 distinguished between two problem-solving perspectives. The conventional perspective is based on the design of a set of general formal rules that are problem content-independent, and as such they are applicable to any problem formally expressed by a set of equations (this is the case, e.g., of probability calculus). The other perspective generates a set of assumptions, principles, and core KBs that are content-dependent (i.e., the problem content is central to the solution process). According to a school of thought, problem-solving brain networks designed through evolution would assign to this perspective. Be all as that it may, Epibraimatics aims to develop a quantitative IPS representation in terms of a set of equations that combine the best elements of the different perspectives, as required by the in situ phenomenon.

7.4.1 Equations on a Napkin

The focus of this section is the spirit rather than the letter of the mathematical IPS equations – the interested readers are referred to the appropriate sources for the technical details. Although the section strips the outline of technical details so that the readers can begin to see the theory's profile, yet it strives for accuracy so that those wishing to fill in the outline will not have to unlearn things learned here. The readers should keep in mind that the difficulty often is not in the mathematics, but in grasping and analyzing the fundamental concepts and principles, in appreciating their beauty, and in selecting the appropriate models. Let us not forget that, one does not truly know anything unless one knows *how* one knows it.

The implementation of the set of space–time equations below is superior when one is aware of the arguments for and against the conceptual framework underlying their derivation. As noted earlier, these particular equations do not constitute the only option conceivable – perhaps they do not even provide the best mathematical formulation possible. A prime goal of these equations is to help one better understand some aspects of the theory and their potential usefulness in establishing a sound IPS approach. In this respect, one should avoid using any mathematical difficulties as a reason to dismiss the whole idea. What Epibraimatics offers is a program of research, not a finished body of knowledge. The road to new and gratifying discoveries is open, as long as the investigator experiences theory in a similar way one experiences *Byzantine hymns*: As a unique combination of heavenly melody and intellectual depth.

One can propose a mathematical theory for deriving action-based solutions of real-world problems by considering, modifying if necessary, quantifying, and blending ideas and principles of different origins (scientific, philosophical, and psychological). It has been said, in a humoristic spirit, that a mathematical theory is not worth its name, unless it can be summarized on a napkin. Based on Eqs. (7.11)–(7.13) and (7.16) and (7.17), the following fundamental set of equations is derived, which pass, indeed, the napkin test:

$$\left.\begin{aligned} \int d\boldsymbol{\chi}(\boldsymbol{g}-\overline{\boldsymbol{g}})\boldsymbol{f}_G(\boldsymbol{\mu},\boldsymbol{g}) &= 0 \\ \int d\boldsymbol{\chi}\boldsymbol{\xi}_s f_G(\boldsymbol{\mu},\boldsymbol{g}) - \boldsymbol{A}[\boldsymbol{f_K}(\boldsymbol{p})] &= 0 \end{aligned}\right\} \tag{7.18a,b}$$

In Eq. 7.18, $\boldsymbol{g}$ is a vector with elements representing quantitatively the G-KB under consideration; $\overline{\boldsymbol{g}}$ is the stochastic expectation of $\boldsymbol{g}$; $\boldsymbol{\mu}$ is a vector with elements that depend on the space–time coordinates and assign proper weights to the elements of $\boldsymbol{g}$ (i.e., they assess the relative significance of each $\boldsymbol{g}$ element in the composite solution sought); f_G is the attribute PDF model at each space–time point (the subscript G means that the model is built on the basis of the core KB), and its shape depends on the TP operator, i.e., the expected information (entropy) form assumed (f_G is a function of $\boldsymbol{g}$ and $\boldsymbol{\mu}$); the $\boldsymbol{\xi}_S$ represents the S-KB available; the form of $A[\cdot]$ depends on the AP operator used; and f_K is the updated attribute model at each space–time point (the subscript K means that the model is based on the blending of the G – and S-KBs). One should notice that a common situation in scientific inquiry is when one has a set of data and a set of equations, and the latter need to be solved in a way that is consistent with the former. In the present approach the two (physical data and equations) are blended together to form the system (7.18). Otherwise said, an epistemology is introduced that generates knowledge by means of the system (7.18). This system may be too complex to be solved in full analytic glory. This is, again, a situation commonly encountered in sciences, which is why a wide variety of computational tools have been developed. The subject will be revisited in the following sections.

7.4.2 Eos and Relative KB Informativeness

Eos was the winged goddess of the dawn who fell in love with handsome Tithonus. She asked Zeus to make Tithonus immortal but she forgot about eternal youth. By failing to include this key element in her request to Zeus, she ended up with a lover made ineffective and helpless with age. *Mutatis mutandis*, the first thing necessary to guarantee the effectiveness of Eq. (7.18) is to make sure that they include key elements with respect to the particular problem. In which case, various questions may arise in the context of the fundamental equations. It is not surprising that the KBs (core and site-specific) constitute a key component of any IPS approach. What is, perhaps, surprising is the occasional insistence on a trivial approach of studying the matter to the exclusion of potentially valuable alternatives. In mainstream data analysis, when faced with the huge task of processing massive amounts of spatiotemporal data resulting to an overwhelmingly high-dimensional statistical model, the predominant approach is to use techniques that can somehow "reduce" the situation to one of a specified dimensionality. It is a classical case of a second-nature mechanistic reaction that is intellectually neither challenging nor demanding. Instead, its goal is to conveniently approach the problem as yet another candidate to which the existing methods and techniques can be applied. But this is precisely the kind of mindset that acts as an obstacle to progress, since it prevents the consideration of any conceptual alternatives, even when these alternatives make more sense than the endless technicalities that wrap themselves in knots. This is a trap that all problem–solution approaches, including dialectical thinking, ought to avoid at any cost.

A logical alternative is that instead of focusing solely on the endless production of internally unrelated and often inconsistent techniques, one should be also concerned about the substantive assessment of the relevant data sources. As we saw in previous sections, Epibraimatics is interested to assess the value (in a relativistic, technical information sense) of the G- and S-KBs involved in IPS. For illustration purposes, we will examine a simple example. Consider a G-KB consisting of the natural law $\frac{d}{dt}X_t = X_t$ and an S-KB that contains the datum $X_0 \sim f_{X_0}$; i.e., due to uncertainty the attribute X_t and its datum is considered random fields, in which case the natural law is stochastic (Section 5.5.3). A solution in terms of probabilities is $f_{X_t} = f_{X_0}\, e^{-t}$, $t>0$. This implies that $I_G = I_S + t$, where $I_G = -\log f_{X_t}$ is the information provided by the law and $I_S = -\log f_{X_0}$ is that inherent in the datum. The information difference is $\Delta I = I_G - I_S > 0$, i.e., the information provided by the G-KB is larger than that by the S-KB, in this case. Since the ΔI increases with t, this difference can become arbitrarily large. The same conclusion may hold in a more general framework, in the sense that a stochastic natural law amplifies the knowledge provided by the case-specific data. In the example above, a symbolic representation of the underlying stochastic reasoning is

$$\underbrace{X_0 \sim f_{X_0}}_{S-KB} \xrightarrow{\text{Physical law}} \underbrace{\begin{cases} X_1 \sim f_{X_1} \\ X_2 \sim f_{X_2} \\ \vdots \\ X_t \sim f_{X_t} \end{cases}}_{G-KB} \tag{7.19}$$

Another interesting example with physical significance is as follows. On the basis of the analysis in Section 7.2 the information inequality $\overline{I_{X_1,\boldsymbol{p}}} \geqslant \overline{I_{X_1|X_2,\boldsymbol{p}}}$ holds, where $\overline{I_{X_1,\boldsymbol{p}}}$ is the average information about $X_{1,\boldsymbol{p}}$ if it was possible to observe it directly, and $\overline{I_{X_1|X_2,\boldsymbol{p}}}$ is the average information about $X_{1,\boldsymbol{p}}$ obtained by observing $X_{2,\boldsymbol{p}}$ (linked to $X_{1,\boldsymbol{p}}$, say, via an empirical relationship). According to this line of thought, the average information obtained by direct observation of $X_{1,\boldsymbol{p}}$ cannot be smaller than that obtained indirectly via $X_{2,\boldsymbol{p}}$. In a similar manner, the difference $\overline{I_{X_1,\boldsymbol{p}}} - \overline{I_{X_1|X_2,\boldsymbol{p}}} \geqslant 0$ measures the uncertainty reduction about $X_{1,\boldsymbol{p}}$ due to observation of $X_{2,\boldsymbol{p}}$. These and similar considerations can play a useful role in KB consistency resolution, in the sense that when some KB elements are inconsistent with some other elements, one may choose to abandon those elements that are less informative in the technical sense of the term.

7.4.3 Working Out the Equations

To call a spade a spade, getting the interpretation right is often more difficult than just working out the equations. In fact, it turns out that the equations governing f_K have a different structure from the interpretation of f_K. While Eq. (7.18) describes how the attribute PDF changes across space–time, the solution f_K is not a material attribute, but rather a description of the likelihood of an attribute occurring. Given f_K, there is a set of rules to calculate specified attribute values such as its mean, mode, and median. The particular shapes of f_G and f_K depend on the TP (information) and AP (conditional) operators assumed (examples were given in previous sections). At the methodological level the worldview inherent in Eq. (7.18) may also include concepts that are individually familiar, but it interprets and assembles them in an unfamiliar way, with potentially far-reaching implications. Accordingly, the thinking mode introduced by these equations probably deserves a deeper analysis by the interested readers. Emphasis on the IPS thinking mode and methodology has a number of reasons (theoretical and practical) discussed throughout the book. One of the conceptual reasons is that, one is driven to unify disparate or contradictory ideas and knowledge bases from different sources and disciplines, and in the process to simplify the corresponding theories used to represent them. One of the practical reasons is that, at times, it is difficult to know whether two different numerical codes are really modeling the same in situ system, since experts are not always aware of the implications of some of the modeling choices they have themselves made.

To paint with a broad brush, Eq. (7.18) recognize the fundamental element that theories, models, and experiments linked to IPS have in common: Human agents (the investigators) have created them, in a way or another. Therefore, Eq. (7.18) describe the investigator's mental representations and associations in light of the available KBs. They are not merely physical equations of the outside world per se, but also equations describing the investigator's inside world (mind functions, world perspectives, etc.). Any rigorous and realistic in situ study cannot neglect mental representations. Judea Pearl (2010) is convinced that, "Statisticians can no longer ignore the mental representation in which scientists store experiential knowledge, since it is this representation, and the language used to access it that determine the reliability of the judgments upon which the analysis so crucially depends." Furthermore, the above considerations may bring to mind Heisenberg's quote: "Contemporary science, today more than at any previous time, has been forced by Nature herself to pose again the old question of the possibility of comprehending reality by mental processes, and to answer it in a slightly different way." The epistemic perspective of Eq. (7.18) should be distinguished from that of pure mathematics. A purely mathematical solution of a problem is viewed as an objective truth, whereas the solution proposed by Eq. (7.18) is rather a "truth-in-the making." The "is vs. becoming" differentiation was originally found in Parmenides' Poem *Περί Φύσεως* (*On Nature*; Section 1.1.2.2): God *is*, whereas the mortals are *becoming*. Parmenides' reflection was that God knows the Truth, but the mortals can only increasingly approximate it by their continuous acquisition and processing of knowledge that is fluid and uncertain. From a psychological perspective, these equations appear to be a consequence of the realization of how useful the Epibraimatics ideas and theories could become in the Conceptual Age, seeking integrative problem-solutions that would optimize mental functions in an evolutionary context rather than mechanistic solutions designed by conventional mechanistic techniques.

The reason I devoted so much of this book to the philosophical and psychological matters underlying the IPS approach is that the majority of quantitative problem–solution methods place too much emphasis on "how" (preoccupied with schemes and procedures to process data), and very little on "why" (understanding the meanings of what we know rather than merely accumulate data). A typical example is medical research. By focusing on hows/schemes rather than on whys/meanings, medical science ended up treating symptoms of a disproportionally larger number of diseases than it can cure. This is because medical research mainly can describe rather than explain. Such a scientific culture makes technicians out of those who profess to practice science, and causes problems that increasingly affect the quality of life. A point due to Aristotle is telling: "Technicians may know that a thing is so, but they do not know why." One can only hope that at some point the hard realities of life will convince the clerkdom of medical research that it is more appropriate to seek a balance between the "hows" and the "whys" of this world. The movement between the practices of the "hows" and the "whys" provides the investigator with an outlook from which to better understand and interpret as significant the gap between them, which can improve medical research.

7.5 The Special Case of Bayesian Maximum Entropy

Equations (7.18) attempt to improve the solution of old problems and they may even suggest some novel and interesting possibilities. These equations could influence the way of thinking and offer valuable insights. For one thing, the shapes of f_G and f_K in Eq. (7.18) depend on the TP information measures (Table 7.3) and AP conditional operators (Table 7.8) assumed. If the B–S information is used in TP, the model f_G has an exponential shape. If the T information is chosen, f_G has a power-law shape, etc. On the other hand, the forms of $\boldsymbol{g}$ and $\boldsymbol{\xi}_S$ depend on the G- and S-KBs assimilated and processed by the AP operator. One special case is the *Bayesian Maximum Entropy* (*BME*) method to be discussed next.

7.5.1 The BME Equations

We are now prepared to derive the BME equations from the fundamental Eq. (7.18). For this purpose, a TP operator in terms of the B-–S entropy (Table 7.3), and an adaptation operator in terms of the statistical conditional (Table 7.8) are assumed. These assumptions yield $f_G = e^{\boldsymbol{\mu}\cdot\boldsymbol{g}}$ and $A\,[f_K] = Af_K$, where A is now a normalization parameter. Under these conditions, Eq. (7.18) reduce to (Christakos, 1990b, 1991b; 2000)

$$\left.\begin{aligned} \int d\chi(\boldsymbol{g}-\overline{\boldsymbol{g}})e^{\boldsymbol{\mu}\cdot\boldsymbol{g}} = 0 \\ \int d\chi\, \boldsymbol{\xi}_S\, e^{\boldsymbol{\mu}\cdot\mathbf{g}} - Af_K(\boldsymbol{p}) = 0 \end{aligned}\right\} \tag{7.20a,b}$$

The $\boldsymbol{g}$ and $\boldsymbol{\xi}_S$ are the inputs to Eq. (7.20), whereas the unknowns are the $\boldsymbol{\mu}$ and f_K across space–time. The kind of KBs the solution ($\boldsymbol{\mu}$,f_K) will be able to account for depends on the choice of the vectors $\boldsymbol{g}$ and $\boldsymbol{\xi}_S$. The stochastic reasoning underlying Eq. (7.20) aims at the most economic way of organizing the KBs, making connections between them, and accounting for basic IPS principles of problem–investigator associations.

Equations (7.20) are the basic equations of BME analysis. They introduce a knowledge synthesis framework that directs an agent's attention toward things one knows about (KBs) and things one does not know about (multisourced uncertainties). A large number of problems can be represented in the form of Eq. (7.20), including space–time mapping of natural attributes, system parameter identification, and the solution of differential equation models of physical laws in light of case-specific databases. For illustration purposes, let us revisit the simple species growth situation of Section 4.3.3 by means of BME analysis. The growth is represented in time by the differential equation

$$\tfrac{d}{dt}X_t = 2X_t, \tag{7.21}$$

where the attribute X_t represents species population at time t with IC, $X_0 \sim N(\overline{X_0},\ \sigma_0^2)$. Eq. (7.21) is the G-KB of the situation, in which case the first of Eq. (7.20) yields

$$\left.\begin{aligned} \int d\chi\, e^{\mu_0+\mu_1(t)\chi+\mu_2(t)\chi^2} &= 1 \\ \int d\chi\, \chi\left[\tfrac{d}{ds}-2\right] e^{\mu_0+\mu_1(t)\chi+\mu_2(t)\chi^2} &= 0 \\ \int d\chi\, \chi^2\left[\tfrac{d}{ds}-4\right] e^{\mu_0+\mu_1(t)\chi+\mu_2(t)\chi^2} &= 0 \end{aligned}\right\} \tag{7.22}$$

at every t. The solution of the system of Eq. (7.22) gives the PDF

$$f_G(\chi,t) \propto\ e^{\overline{X_0}\,\sigma_0^{-2}e^{2s}\chi - 0.5\,\sigma_0^{-2}e^{-4s}\chi^2}. \tag{7.23}$$

As it happens, Eq. (7.23) coincides with the solution obtained by classical stochastic analysis (Gardiner 1990), a fact that confirms BME's nesting property: its ability to incorporate the successes of its predecessors. Beyond that, a definite advantage of the BME method is that it can work with models of arbitrary complexity, and assimilate a variety of relevant knowledge sources, in addition to the law (7.21). Indeed, BME can improve the solution (7.23) by subsequently assimilating any form of site-specific data that may become available. For example, let the S-KB consist of the probabilistic datum $f_S(\chi,t)$, $\chi \in [a_t,\ b_t]$, at each t, representing uncertain yet credible information about the attribute. Equation (7.23) can be properly adapted in light of this S-KB . Assuming an SC and an EC probability (Table 7.8), the final PDF is given by, respectively,

$$\left.\begin{aligned} f_K^{sc}(\chi,t) &= A^{-1} f_S(\chi,t) f_G(\chi,t) \\ f_K^{ec}(\chi,t) &= (2A-1)^{-1}[2f_S(\chi,t)-1] f_G(\chi,t) \end{aligned}\right\}, \tag{7.24a,b}$$

where $A = \int_{a_t}^{b_t} d\upsilon f_S(\upsilon,t) f_G(\upsilon,t)$ in light of the S-KB. Alternatively, Equations (7.24) may be viewed as the BME solutions of the physical law (7.21) as a function of t. The take home message is that, unlike the standard stochastic solution Eq. (7.23), the BME solution (7.24) can account for a variety of site-specific data sources, can have different shapes (SC, MC, EC, etc.), and offer assessments of the uncertainty of the various possible X_t realizations in time that do not involve any of the technical approximations and restrictions of the conventional solutions.

As noted earlier, Table 7.9 shows some examples of SC probabilities P_K^{sc} derived on the basis of Eq. (7.20), assuming two representative cases of S-KB. This KB consists of data X_d (at a set of points $\boldsymbol{p}_d = \boldsymbol{p}_h \cup \boldsymbol{p}_s$) that can be divided into hard X_h data (at a set of hard data points $\boldsymbol{p}_h$), and soft (uncertain) data X_s (at soft data points $\boldsymbol{p}_s$). The I_S and I_k denote intervals of attribute values. In the second case of Table 7.9, there exist soft data at the solution (prediction, etc.) space–time points, as well.

In this case, the probability model of the solution starts as $P_G[X_{\boldsymbol{p}_k} = \chi_{\boldsymbol{p}_k}]$, then it is adapted in light of $P_S[X_{\boldsymbol{p}_k} = \chi_{\boldsymbol{p}_k}]$ to lead to the final $P_K^{sc}[X_{\boldsymbol{p}_k} = \chi_{\boldsymbol{p}_k}]$, where the three probability models are linked to the associated epistemic states. The corresponding MC (P_K^{mc}) and EC (P_K^{ec}) probabilities can be calculated from P_K^{sc} of Table 7.9 using Eq. (6.6) and (6.7). One may, also, consider the possibility to define the uncertainty of a problem–solution in terms of the uncertainty function introduced in Section 4.5.1. In particular, the uncertainty of a solution $\chi_{\boldsymbol{p}}$ obtained from Eq. (7.20) may be determined by the SC uncertainty $U_K^{sc}[\chi_{\boldsymbol{p}}]$, and it is also possible to derive a range for the SC uncertainty:

$$(A-1) + U_G\left[\chi_{\boldsymbol{p}}\right] \leqslant U_K^{sc}\left[\chi_{\boldsymbol{p}}\right] \leqslant A^{-1} U_G\left[\chi_{\boldsymbol{p}}\right], \tag{7.25}$$

where $U_K^{sc}[\chi_{\boldsymbol{p}}] = U_G[\chi_{\boldsymbol{p}}|S]$, and $A = 1 - U_G[S]$. In light of Eq. (7.25), the smaller the prior uncertainty $U_G[S]$ of the S-KB is, the smaller will be the range of possible values of the posterior uncertainty of the solution, $U_K^{sc}[\chi_{\boldsymbol{p}}]$.

7.5.2 In Situ Solution of the BME Equations

A closer look reveals that the implementation of Eq. (7.20) in the study of in situ systems has a twofold goal: To represent the problem externally using the relevant KBs, and to order the KBs internally and assess the relations among them in a way that meaningful problem–solutions are obtained. Metaphorically speaking, Eq. (7.20) resemble the fisherman's net: the kind of fish the net catches depends on the choice of the net used (how fine the net is, its size, etc.).

The formulation of the G-KB and S-KB depends on the in situ conditions and objectives of the problem considered. In certain in situ cases only a limited KB is needed, whereas in some others a much more detailed and complete KB is necessary in order to solve the same problem. Assume, e.g., that the problem is crossing a water channel from point A to point B using a boat. In a clear day one can see from A to B, and the KB required to solve the problem is minimal (cross the channel using only visual information). If, however, the day is foggy, the solution of the same problem (crossing the channel) requires that the KB should include the information provided by a compass, data about wind velocities and currents, etc. In addition, the considerable uncertainty (due to existing conditions, such as fog, instrument and dataset imperfections) allows only a finite degree of confidence that the derived solution will bring one within a certain distance of the destination B. Hence, if the cost of missing B is high, one may want to enhance the KB (possibly, at an extra expense) so that the distance from the poinr B is as small as possible. Under these conditions, the difficulty in solving Eq. (7.20a) with respect to μ will depend on the complexity of the vector $\boldsymbol{g}$ which, in turn, depends on the kind of G-KB it represents. If, e.g., $\boldsymbol{g}$ includes only a linear empirical model, the solution $\boldsymbol{\mu}$ is easy to obtain. If, however, $\boldsymbol{g}$ includes physical laws in terms of partial differential equations, the solution $\boldsymbol{\mu}$ will be more difficult to obtain (analytically or computationally). Similar is the case of Eq. (7.20b): the difficulty in carrying out the integration that leads to f_K across space–time will depend on the complexity of $\boldsymbol{\xi}_S$ which, in turn, depends on the kind of *S*-KB incorporated by $\boldsymbol{\xi}_S$. In sum, there is not a generally applicable (analytical or computational) approach for solving the BME equations. Rather their solution depends primarily on the form of $\boldsymbol{g}$ and $\boldsymbol{\xi}_S$, as it should be the case with a living experience method like BME (Section 7.1.2). An approximate solution of Eq. (7.20) is often sought, which is a common practice in scientific investigations.[21] Methodologically (Section 7.3.5.2), Eq. (7.20) introduce a merging of different inputs (KBs about the phenomenon at hand), and establish connections between these inputs to create new emergent structures in the form of the solution. Some input elements are projected into the solution, some are not, and some others are fused in the merging. The solution's emergent structure is not necessarily present in the problem inputs, but arises through *composition* (integrating case-specific KB elements to generate relations not existing in input states), *completion* (recruiting background cognition sources), and *selective projection* (some elements and links are projected, some are not, some are fused).

7.5.3 Generality of the Fundamental Equations

The matrix of issues unfolded in the previous sections revealed the fact that the fundamental Eq. (7.18) establish a concise mathematical setting that summarizes a host of theoretical and applied results. These results depend on the choice of the equation parameters, which in turn depend on the epistemic condition of the agent and the problem objectives. The analytical forms derived render the solution exposing problem characteristics that may otherwise remain unidentified, and making the eventual computational manipulations more stable and efficient.

For the readers' convenience, Table 7.10 gives a list of the method's features of theoretical and practical value. It is noteworthy that several spatiotemporal regression techniques (including Kriging) are special cases of Eqs. (7.20), if some restrictive assumptions are imposed on its parameters (e.g., *G*-KB is limited to low-order dependence functions and *S*-KB to hard data). However, this does not imply that Kriging is equivalent to BME. A BME method that certain technical simplifications reduce to Kriging is no more a BME method, in the same way that a three-dimensional phenomenon that technical simplifications conveniently reduce to a unidimensional phenomenon is no more a three-dimensional phenomenon. This logical reduction process has escaped the analysis of Hussain et al. (2010): the analysis wrongly assumed that it used the BME method to study precipitation distributions when, in fact, it merely used the Kriging method. Fuentes and Raftery (2005) developed a spatial Bayesian melding technique integrating observations

[21] It may seem paradoxical, but exact sciences are dominated by the idea of approximation.

Table 7.10 BME features of theoretical and practical significance

Involves evolutionary principles based on mental functions that embrace diverse phenomena and interdisciplinary descriptions in a single scheme.	Offers complete system characterization in terms of prediction probability laws (non-Gaussian, in general) at every grid point, and not merely a single prediction at each point.
Processes multisourced uncertainties (conceptual-technical, ontic–epistemic).	Represents space–time patterns by means of rigorous theoretical dependence models.
Assumes space–time coordinate systems that accommodate Euclidean and non-Euclidean space–time metrics.	Uses nonlinear attribute predictors (rather than restrictive linear/linearized estimators of mainstream statistics).
Various knowledge bodies can be used, such as soil texture triangles.	Allows multiple attributes (*vector* or *co*-BME) and different space–time supports (*functional* BME).
Accounts for attribute variability and the underlying physical mechanisms.	Uses operational assimilation rules that are effective and considerably flexible.
Relies on a knowledge synthesis approach (rather than on mechanistic curve fitting and *ad hoc* trend surface techniques), which allows it to incorporate theoretical models, scientific theories, and empirical relationships.	Applies in a variety of problems: solution of differential equations representing physical laws; geographic information systems and decision analysis; inverse problems; data fusion and image processing.
Accounts for secondary data (*fuzzy* sets) and *categorical* variables.	Incorporates *high-order* moments; e.g., skewness effect on space–time prediction.
Space–time regression and geostatistical kriging are special cases of BME, which compares favorably with mainstream Kalman techniques.	Extensions include the *Generalized* BME that directly accounts for heterogeneous/non-Gaussian data distributions.

and numerical model estimates. De Nazelle et al. (2010) have shown that, although it is almost two decades older than the Fuentes–Raftery Bayesian (FRB) technique, space–time BME is a more general and realistic approach. Among other things, while FRB relies on the restrictive assumptions of a Gaussian and linearized model, the BME does not make such assumptions, since it uses a more transparent nonlinear and non-Gaussian approach. As de Nazelle and coworkers pointed out, these advantages make BME a better tool than FRB in a contentious real-world policy context. In some cases standard Bayesian analysis passively accepts assumptions that may disagree with physical reality. This does not seem to bother some investigators (Dominici, 2002: 12): "if there is no desire to incorporate prior information into the analysis, then vague prior distributions are the default choice," she argues, but without explaining when prior (core) physical knowledge about a phenomenon can be undesirable and what exactly is the substantive role of the "vague priors" that replace it. If "the priors that Bayesians commonly assign to statistical parameters are untested quantities" Pearl (2010: 3) warns these investigators, then the analysis progressively eliminates crucial knowledge that could be incorporated into the priors.

Over the years, developments (theoretical and applied) have followed a variety of paths, depending on the discipline and in situ environment (D'Or and Bogaert

2003, Kovitz and Christakos 2004b, Bogaert 2002, Kolovos at el. 2002, Yu et al. 2007b, Christakos 2006, Bogaert and Fasbender 2007, Fasbender et al. 2007, Tuia et al. 2007, Christakos 1998, Yu and Christakos 2006, Yu et al. 2007a). The theory is continually expanded to cover broader conceptual frameworks, whereas computational techniques have been successfully used in real-world studies in a variety of scientific disciplines. As a result, the BME theory and computation are vital components of a purposeful, *gnosis*-based IPS. Each component plays its own indispensable role, and the two cooperate closely with each other to generate informative solutions and new gnosis. Theory is used to enhance one's receptivity to in situ experiences that will stretch and pull them into new shapes of insight and understanding. In such a context, there is no doubt that "one needs to think theoretically in order to solve computationally," which is the fillip that concludes this section.

7.6 Space–Time Prediction: Tibet's Oracle and Other Stories

During the 1959 crisis, Tibet's Oracle made the prediction that Dalai Lama's best course of action was to flee Tibet for India and Western control, which is what Dalai Lama did. As it turned out later, the holy monks of the Oracle were on CIA's payroll (Roberts 1997: 130–132). The didagma[22] here is that prediction can be influenced by many different and often unexpected factors, which is why prediction is often a risky business. But, it is also a fascinating business. Within the space–time domain experienced by human agents, cognitive science has long recognized that it is the power of prediction that has fueled the intellectual arms race and paced the evolution of biological intelligence (Freeman 2000).

Attribute prediction is conditioned on a number of factors, including the nature of the composite space–time continuum, the spatiotemporal variation features of the attribute, the conceptual and technical uncertainties, the core and case-specific KBs available, the prediction accuracy sought, and other study objectives that vary from one problem to the other.

7.6.1 Superposition Property and the Cubist Movement

Prediction is a crucial human activity that requires rational and sensory investment. In fact, the difference between the various space–time prediction methods (BME, Kriging, Kalman, Bayesian hierarchical, etc.) lies in how they exercise an investigator's faculties of reasoning and sensing, and the generative tension between these two. Indeed, BME provides the complete series of PDFs f_K across space–time

[22] Didagma (or $\delta\iota\delta\alpha\gamma\mu\alpha$) denotes distilled knowledge (the lesson learned, what one must keep in mind).

capable of addressing the direction of the dialectic between reason and experience. Each f_K includes all possible realizations of an attribute $X_{\boldsymbol{p}}$ and the associated probabilities at each space–time point $\boldsymbol{p}$. Before the event (e.g., before a definite observation is made at $\boldsymbol{p}$), these realizations exist in *superposition*: in general, individual realizations of $X_{\boldsymbol{p}}$ cannot be predicted with certainty – only their respective probabilities can be derived before the event. However, after the space–time-dependent PDFs have been obtained, a variety of attribute realizations can be generated. Although a full discussion would be a digression here, three points are worth noticing. First, each $X_{\boldsymbol{p}}$ realization consists of a series of attribute predictions at a large number of space–time points (usually at the nodes of a suitable grid). Second, each realization has a different probability of occurrence and provides complementary information aiming at an improved understanding of the space–time attribute distribution. Third, each realization may be viewed as a map or image of the attribute distribution (hence the terms "mapping" or "imaging" used to refer to the process leading to the construction of the map or the image).

The superposition property and the resulting multiplicity of the f_K-generated spatiotemporal realizations (or images) may remind one of the *Cubist* Movement in art: instead of depicting an entity from one viewpoint only, one depicts the entity from a multitude of viewpoints, thus represents it in a broader context. The visible is the totality of possible images obtained from different space–time viewpoints. The study of multiple images requires close scrutiny, reflection, and analysis of not only the content of the images, but of the agent's cognition powers and innermost thoughts. Among the various possible realizations generated by f_K, there are a few that possess features of particular interest in the context of the particular in situ situation. For example, starting with f_K we can select a specified space–time attribute prediction (or estimation), $\hat{X}_{\boldsymbol{p}}$, of the actual (but unknown) $X_{\boldsymbol{p}}$ value at any point $\boldsymbol{p}$ of interest. Speaking to the point, the problem–solution in this case is expressed in terms of the corresponding predictions $\hat{X}_{\boldsymbol{p}}$ across space–time.

7.6.2 Distinctions from Mainstream Data-Driven Techniques

IPS duly recognizes that an attribute prediction approach that relies solely on the available (and often limited) datasets is of limited usefulness and can produce potentially misleading results. The reason is rather simple. One of the main arguments of purely data-driven (PDD) techniques (statistical regression, Kriging, time series, etc.) is that they can be used in cases in which the physical mechanisms underlying the in situ phenomenon are very complex, uncertain, and for the most part unknown, making it impossible to derive a scientific theory or a physical law for rigorous explanation and prediction purposes. However, in addition to serious self-reference issues (Section 9.4), there is an obvious logical contradiction in the PDD line of thought: While it recognizes that the phenomenon is poorly understood in terms of the available dataset, nevertheless, it claims that the same dataset is sufficient for PDD prediction purposes. Otherwise said, PDD neglects the fact that a prerequisite of meaningful prediction is a good understanding of the phenomenon. This does not make sense, unless PDD is based not on scientific but on magical thinking (bringing to mind Carlos Casteneda's journeys in the "land of silent knowledge").[23]

To avoid as much as possible this sort of logical paradoxes and contradictions, the BME approach is built in a way that does not limit the notion of prediction to the available datasets and the associated data-fitting schemes. Instead, it considers prediction from a wider perspective that involves the core KB and also a host of relevant site-specific KBs. This is a sound way of acknowledging that in situ phenomena cannot be forced to fit into a purely PDD straitjacket. Reality is too multidimensional and manifold to be represented by one single technique, and interpreted out of a limited dataset. When this happens, the results obtained say more about the PDD technique used than about the phenomenon under consideration. Furthermore, the fact that BME analysis generates the complete f_K across space–time has considerable advantages compared to techniques relying on the convenience of the mean squared error minimization (MSEM) criterion to produce a single value (prediction or estimate $\hat{X}_{\boldsymbol{p}}$ of $X_{\boldsymbol{p}}$) at each space–time point $\boldsymbol{p}$. The generated PDFs across space–time allow considerable flexibility in the choice of a predictor (or estimator) that depends on the problem conditions and the goals of the study. A few examples of predictors $\hat{X}_{\boldsymbol{p}}$ calculated from f_K are shown in Table 7.11. Other forms of predictors can be derived so that they optimize suitable objective functions for the problem at hand.

Another considerable improvement is that the BME predictors are *nonlinear* and *non-Gaussian*, in general. The best choice of a predictor is not known in advance, but emerges during the stochastic reasoning process that is not restricted by any a priori assumptions concerning predictor's shape (linear, normal, etc.). Mean prediction is a popular choice in the literature. As already mentioned, the mean prediction can be derived from the MSEM criterion in a technically straightforward way. Moreover, the MSEM prediction is naturally linked to Gaussian probability. The above two convenient features of MSEM prediction have made it the prominent choice of many theorists (it greatly simplifies analytical calculations and,

Table 7.11 Examples of space–time predictors

BMEmode (represents the most probable realization):	$\hat{X}_{p,\text{mode}} : \max_{\chi_p} f_K$	(7.26)
BMEmean (minimizes the mean squared prediction error):	$\hat{X}_{p,\text{mean}} = \int_{-\infty}^{\infty} d\chi_p\, \chi_p f_K$	(7.27)
BMEmedian (minimizes the absolute prediction error):	$\hat{X}_{p,\text{median}} : \int_{-\infty}^{\chi_{p,\text{median}}} d\chi_p\, f_K = 0.5$	(7.28)

[23] It is not ususual that the real motivation for taking refuge in inadequate techniques is the investigators' fear that their overseers could think that they lack understanding and predictability, which might result in the loss of recognition and funding for one's projects, or the loss of corporate clients. Since it is often too difficult to measure real progress, the users of inadequate techniques plausibly expect to be rewarded for their analysis and predictions, even if the analysis is overly simplistic and unreasonable, and the predictions unsubstantiated.

hence, it dominates the contents of thousands of statistics books and journal papers), as well as of many expert practitioners (it is constantly praised for its simplicity and practicality, and is heavily favored by most statistics software). The same attractive MSEM features can also turn out to be serious drawbacks. Let us mention two of them. First, due to the MSEM criterion, the resulting mean predictor is not robust, in the sense that very small and/or large $X_{\boldsymbol{p}}$ values can distort it. Second, many in situ attributes do not actually follow the Gaussian curve assumed by the mean predictor. For example, in the case of the Cauchy probability curve (which arises in many real-world situations, and is characterized by its thicker tails compared to the Gaussian curve), a basic result of sampling theory is violated: the accuracy of the mean predictor does not improve with sample size. Fortunately, other predictors do not share the drawbacks of the MSEM predictor, which demonstrates the value of a method's flexibility that allows the choice of different predictor forms, when necessary (e.g., unlike $\hat{X}_{\boldsymbol{p},\mathrm{mean}}$, the $\hat{X}_{\boldsymbol{p},\mathrm{median}}$ is robust and can be used in BME prediction, depending on the problem's context and content). One can find in the literature several comparative studies involving space-time prediction techniques. For the readers benefit, I mention a few of them here. Douaik et al. (2003) showed that BME produced reliable soil salinity estimates, whereas Kriging (with hard and/or soft data) failed to predict soil salinity accurately. We already mentioned the work of Hussain et al. (2010) who compared Kriging with hierarchical Bayesian interpolation, and De Nazelle et al. (2010) who compared BME with a Bayesian melding technique in the case of ozone distributions. Yet another interesting comparative study was done by Dick J. Brus and Gerard B.M. Heuvelink (2007) who used the Kriging, BME and Markov techniques to map soil types and soil properties from soil observations and explanatory information.

7.6.3 How to Look and How to See

A space–time prediction approach is distinguished not only for its space–time prediction effectiveness and versatility, but also for its heuristic power that offers valuable guide in the study of an in situ problem. As noted earlier, the predicted attribute values are used to create spatiotemporal maps, which can be scientifically interpreted to provide a useful picture of reality, and generate science-based decisions. What I would like to add here is that mapping does not merely concern the geographical distribution of attributes, which means that the significance of *visualization* should be neither overvalued nor undervalued (Section 9.1.1; also, Skupin 2002; Kaiser et al. 2004). A meaningful visualization takes into consideration the background, objectives, and expertise of the map user. Actually, learning *how to look* is much simpler than learning *how to see*. The latter requires a combination of deep understanding, introspection, and knowledge-based speculation. Not knowing how to see beyond appearances into the actual phenomenon represented by a spatiotemporal map may lead to conflicts and nonsensical conclusions.

A collection of predictions across space–time can be visualized and evaluated in different ways by the experts. This visualization must carefully take into consideration the anamorphic nature of the different kinds of images, which can make them problematic windows to the real-world. Reflecting on the available KBs is the key to avoid the risk of becoming hostage to the "reality" the images often allow one to view. For illustration, Fig. 7.6a presents one of a set of three-dimensional temperature maps generated in a subregion of the thermometric field of Nea Kessani (Greece; Yu et al. 2007b). The field solution represented by this map was the synthesis of core knowledge (in the form of the heat transfer law) and site-specific data (geology and geophysics of the region, and vertical drill holes), which is the background on the basis of which an expert understands and interprets the maps. Using a comparative analysis based on in situ data, Hwa-Lung Yu and coworkers showed that temperature maps like that in Fig. 7.6a provide a more realistic representation of the actual phenomenon than maps obtained from mainstream analytical and computational methods of solving partial differential equation models. For example, unlike the solutions derived by these mainstream methods, the map of Fig. 7.6a is in agreement with empirical quartz geothermometry analysis (Yu et al. 2007b). A final point worth noticing is that in the setting above, a key issue is the threefold relationship between (i) the problem–solution (in this case, the map) as a model of reality, (ii) reality itself, and (iii) the expert who is the link between the two. Resorting to a metaphor, the "model-reality-expert" association may be exemplified, at least to some extent, in terms of the map-territory-traveler relationship.

An important issue that has not attracted due attention by the mainstream literature is that a specific prediction may be directly linked to a variety of objectives that vary from one problem to the other. For example, when the prediction concerns major hazards, one can define two useful parameters: The *warning time*, W_t, which is the "lead time" necessary for a prediction to be useful; and the *monitoring time*, M_t, which determines how far into the future the target event

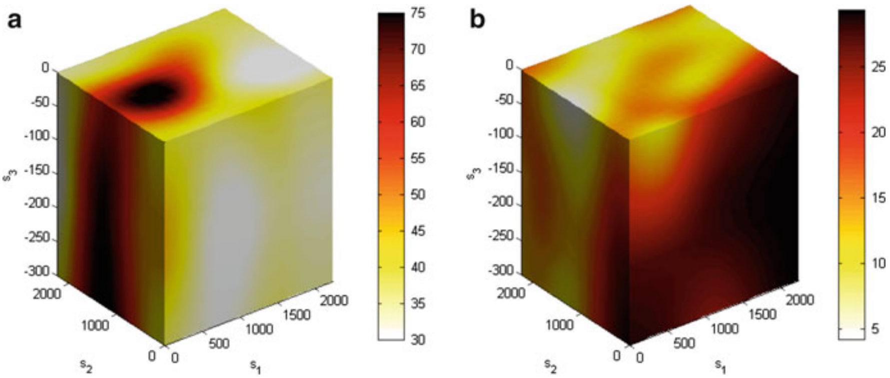


Fig. 7.6 (**a**) Three-dimensional BME temperature map (°C) in a subregion of the thermometric field of Nea Kessani (Greece). (**b**) Associated estimation error variance map (°C^2)

(epidemic outbreak and spread, major earthquake, destructive tornado, etc.) can occur and the prediction still be considered adequate. The W_t depends on the necessary actions before or after the target event (e.g., how long it takes to evacuate an area to be hit by a tornado or to prepare a population for an upcoming epidemic). There generally is more flexibility in assigning a value to M_t. Subsequently, the prediction period can be defined by $P_t = M_t - W_t$. The warning time, W_t, is the "lead time" necessary for a prediction to be useful and the monitoring time, M_t, determines how far into the future a target event can occur and the prediction still be considered correct and useful. A prediction is often considered adequate if it falls within the prediction period P_t of some target event. Matters such as the above offer additional support to the Epibraimatics premise that a space–time prediction is rarely an end by itself. Instead it should be always considered and evaluated in a larger framework that includes a variety of study objectives, such as those discussed in the previous lines.

7.7 Problem–Solution Accuracy

In Jean-Luc Godard's "Band of Outsiders," a miscalculation delays the seemingly perfect plan of two friends to make a big score in life, resulting in a confrontation that has dire consequences. Godard's masterpiece movie shows that certainty can be a dangerous state of knowing and that even a perfect plan is at the mercy of an unexpected event, a dependence that can be expressed in the most dramatic way.[24] Interestingly, research in modern neurophysiology tells us that an agent being certain that is correct has nothing to do with how correct the agent actually is. Instead, certainty often arises out of involuntary brain mechanisms that function independent of reason – in a similar way that love and anger do (Burton 2008). Certainty has the evolutionary advantage that makes humans feel good and allows them not to spend too much time thinking about a problem. Unfortunately, at the same time, it can impair one's good judgment and limit one's critical reasoning and conceptual flexibility.

7.7.1 The Geese of the Capitoline Hill and the Wise Confucius

The hard realities of the unknown and the unexpected that are linked to any genuine inquiry strongly emphasize the importance of a rational agent being prepared to handle unexpected problem–solutions with adverse consequences. The same

[24] Scientists could potentially learn something from Godard's movie. A few decades ago the biologist Paul Ehrlich predicted with certainty that a considerable part of the American population will die of starvation (Ehrlich 1968). The irony is that the opposite, dying of obesity, would have been a better prediction.

unknown makes it necessary to leave room for a culture of skepticism, and a healthy dose of doubt in human investigations.[25] A culture of *skepticism* should involve some kind of a measure of the solution *accuracy* that provides a sense of *awareness* concerning the unknown and the unexpected. Metaphorically speaking, accuracy assessment that expresses awareness might act like the geese of the Capitoline Hill that timely warned the Romans of the unexpected Gallic night attack.[26] Understanding the meaning of accuracy in the specified awareness context is absolutely essential for an adequate communication among investigators, as well as when the investigators suggest solutions to others (managers, policy, and decision makers; Wang et al. 2008).

In sciences, accuracy often refers to the degree to which a given attribute is considered correct and free from various sources of potential error. For example, an attribute prediction specified as 30 ± 0.5 has an accuracy of ± 0.5 (i.e., its true value is expected to fall in the range 29.50–30.50). In this setting, problem–solution accuracy is closely related to knowledge reliability issues. Because of the agent's cognitive condition, the data insufficiency (both in terms of quality and quantity), and the inherent randomness of the X_p attribute distribution, obtaining the *exact* solution is often not a realistic possibility. Instead, an accuracy assessment of the approximate solution (say, the space–time prediction $\hat{X}_p$) is sought that offers us an idea of "how much we *do not* know," or "how much we *cannot* know." This is what wise Confucius meant when he uttered that,

> Real knowledge is to know the extent of one's ignorance.

The term "accuracy" may assume various interpretations, emphasizing either its qualitative or its quantitative aspects. The accuracy of an IPS technique can be assessed before or after the event. Although *before the event* accuracy assessment is usually more common in practice, *after the event* accuracy assessment is useful to assess the performance of a technique and provide guidance for its calibration and improvement. A rather straightforward "after the event" accuracy assessment is obtained in terms of the fit between the predicted and the measured attribute PDFs. For illustration, Fig. 7.7 refers to the ^{137}Cs soil contamination (in Ci Km^{-2}) of the Bryansk region (Russia) due to the Chernobyl fallout, and presents a comparison in terms of *QQ* plots of the quintiles based on the raw (measured) PDFs of soil contamination versus quintiles based on the predicted PDFs (Savelieva et al. 2005). These *QQ* plots show a close fit between the predicted and raw PDFs, thus demonstrating the excellent accuracy of space–time analysis, and also offering valuable guidance for its further improvement.

[25] Yet, many investigators submit their results with the studied hypocrisy expected of a contribution to a scientific journal.

[26] When the Gauls besieged Rome in 390 BC, the Romans took refuge on the Capitoline Hill. One night the Romans were woken by the squawking of the geese in the temple of Juno, just in time to catch a Gallic attack, and force the Gauls to retreat (Dixon-Kennedy 1998).

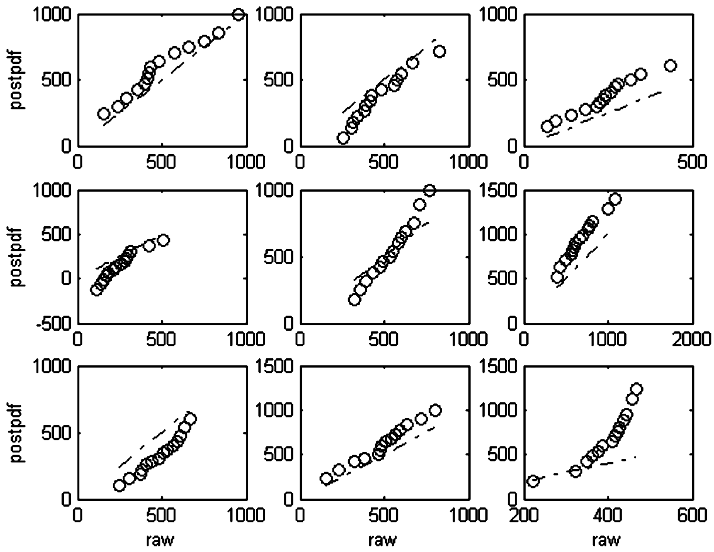


Fig. 7.7 *QQ*-plots comparing raw PDF (*circles*) vs. BME posterior PDF (*dashed line*) of ^{137}Cs soil contamination at various locations (Bryansk, Russia); Savelieva et al. (2005)

7.7.2 Accuracy in Terms of Prediction Error

Some people find it surprising that uncertainty may be also the natural outcome of the increasingly larger amounts of data generated on an everyday basis worldwide. These people should not, however, forget that the larger the island of knowledge, the longer the shoreline of wonder and uncertainty. And the larger the uncertainty about one's predictions, the bigger the need to obtain a sound assessment of the accuracy of these predictions. Assume that the problem is the prediction of the X_p attribute distribution across space–time. Viewed as a "before the event" measure of the agent's uncertainty about the X_p distribution, accuracy is often associated with *prediction error* in a technical sense. This seems a reasonable thing to do, since research in neurosciences has shown that the coding of prediction errors may represent a basic mode of brain activity that contributes to the processing of sensory information and behavioral control. In fact, neurons in brain structures appear to code prediction error in relation to rewards, punishments, external stimuli, and behavioral reactions (Schultz and Dickinson 2000). Also, prediction errors can be used for behavior selection or learning.

Quantitative accuracy measures in the form of prediction errors, intervals, and sets in a composite space–time domain are readily available from the corresponding PDF model. The f_K at each space–time point $\boldsymbol{p}$ is generally expressed by Eq. (7.18b) or (7.20b), in which case the accuracy of attribute prediction depends on the shape of the PDF. More specifically, the accuracy can be defined in a straightforward manner when (7.20b) has a single maximum. Otherwise, the prediction accuracy should be considered separately for each maximum. For f_K with a single maximum, one can further distinguish between symmetric and asymmetric cases. If f_K is symmetric around the single maximum, the latter coincides with the $X_{\boldsymbol{p}}$ mean. Popular, although not unique and by no means "perfect," accuracy measures are the prediction *error standard deviation* and *mean absolute error*,

$$\sigma_{X,\boldsymbol{p}} = \overline{\left[\left(X_{\boldsymbol{p}} - \hat{X}_{\boldsymbol{p}}\right)^2\right]}^{1/2}, \tag{7.29}$$

and

$$\eta_{X,\boldsymbol{p}} = \overline{\left|X_{\boldsymbol{p}} - \hat{X}_{\boldsymbol{p}}\right|}, \tag{7.30}$$

respectively, which are calculated at each point $\boldsymbol{p}$ of the X_p's domain. In Fig. 7.6b, a three-dimensional map of the $\sigma^2_{X,\boldsymbol{p}}$ is plotted that is associated with the temperature map of Fig. 7.6a. Naturally, there are *pros* and *cons* with each one of the above accuracy measures (Willmott and Matsuura 2005). Mathematical optimization in terms of $\sigma_{X,\boldsymbol{p}}$ is usually analytically more tractable than in terms of $\eta_{X,\boldsymbol{p}}$. The $\sigma_{X,\boldsymbol{p}}$ is closely linked to the Gaussian law, whereas the $\eta_{X,\boldsymbol{p}}$ is less sensitive to large prediction errors than $\sigma_{X,\boldsymbol{p}}$ (in $\eta_{X,\boldsymbol{p}}$ all individual errors are weighted equally, whereas $\sigma_{X,\boldsymbol{p}}$ gives relatively high weights to large errors).

Confidence intervals can be readily defined from the prediction uncertainty (7.29). Traditionally, confidence intervals are such that the probability of the predicted value falling on the left part of the interval is equal to that of falling on the right part. In the case, e.g., of a Gaussian f_K there is a 95% confidence that $X_{\boldsymbol{p}}$ lies in the interval $\hat{\chi}_{\boldsymbol{p}} \pm 1.96\,\sigma_{X,\boldsymbol{p}}$, where the predicted value is $\hat{\chi}_{\boldsymbol{p}} = \hat{\chi}_{\boldsymbol{p},\mathrm{mode}} = \hat{\chi}_{\boldsymbol{p},\mathrm{mean}}$. Under certain conditions, a useful formula is valid (Christakos 2000: 150): $\sigma_{X,\boldsymbol{p}} \approx [-(\frac{d^2}{d\chi^2}f_K)^{-1}f_K|_{\chi=\hat{\chi}}]^{1/2}$. In the case of an asymmetric f_K, the $\sigma_{X,\boldsymbol{p}}$ and $\eta_{X,\boldsymbol{p}}$ do not necessarily offer a satisfactory accuracy description, and the complete picture provided by f_K may be needed at each point $\boldsymbol{p}$. Nevertheless, in some special cases a confidence width can be defined. Let f_K be a single maximum PDF, and choose a probability value $\eta = P[\hat{\chi}_{\boldsymbol{p}} - a \leqslant \chi_{\boldsymbol{p}} \leqslant \hat{\chi}_{\boldsymbol{p}} + b]$. The choice depends on the problem under consideration, whereas the coefficients a, b are such that $f_K(\hat{\chi}_{\boldsymbol{p}} + b) = f_K(\hat{\chi}_{\boldsymbol{p}} - a)$. Then, with probability η, it is valid that $\chi_{\boldsymbol{p}} \in [\hat{\chi}_{\boldsymbol{p}} - a,\, \hat{\chi}_{\boldsymbol{p}} + b]$. While for an asymmetric f_K, in general $a \neq b$, for a symmetric PDF, $a = b$ (as should be expected).

For an interdisciplinary thinker, the summary accuracy measures considered above have an intense pragmatic flavor. These measures bring to mind David Hume's attempt to defend epistemic contemplation in terms of arguments, like, "Accuracy is, in every case, advantageous to beauty, and just reasoning to delicate sentiment" (Hume 1963). The thinker's concern, actually, is to avoid the mechanistic incorporation of the summary accuracy measures into the IPS approach. The interdisciplinary perspective is correct when it points out that under the influence of the pure functionality mindset that currently prevails many technical fields, summary measures assume a form that could limit the investigator's role to merely operational. On the other hand, a reality check makes it necessary that an agent obtains some credible idea of how much one may not know, even if this idea is limited. After all, this limitation would be expected, since, as is the case with any assessment of reality involving human judgment, the summary measures also reflect agent's epistemic state of incomplete knowledge, and include a non-negligible amount of uncertainty themselves (these issues are at the center of debates about what is an adequate pollution estimate; Szpiro et al. 2007 and Liao et al. 2007). To improve matters, Epibraimatics suggests that more than one accuracy measures would be sought for the same phenomenon, and then perform a comparative analysis of the results. Moreover, summary accuracy measures should not be used for any purpose whatsoever, before they have been adequately interpreted in terms of the scientific and other kinds of knowledge about the phenomenon under study. The interpretation issue becomes even more important in multidisciplinary problems.

7.7.3 Solution Accuracy as a Doubt Generator

As the analysis in the above sections shows, the quantitative accuracy assessment is not always a straightforward affair. In addition to the technical ones (tractability, normality, robustness, sensitivity, etc.), important conceptual issues include the following. First, one may plausibly question the proper meaning of a solution accuracy measure (such as prediction error standard deviation, confidence intervals and sets) when the actual value is not available to compare it with the predicted one. Instead, measures assessing accuracy in terms of an expected deviation (i.e., averaged over many possible realizations) are considered, which cognitively is a very different matter. Second, as conceived above, quantitative accuracy is associated with an approximate solution. It is preferable to not assign any absolute meaning to the term "accuracy," when the exact solution is not available. There are cases in which an approximate solution is not an option and, therefore, suggesting an accuracy measure seems nonsensical. One cannot consider, e.g., as an acceptable solution getting a telephone number correct to 1% (i.e., a 1% accuracy assessment is meaningless in this case).

As noted earlier, each space–time predictor has certain advantages as well as disadvantages when applied in real-world problem–solution. This is also the case of the associated predictor accuracy measures, especially when multidisciplinary knowledge bases and different uncertainty sources are involved in IPS. Last but not least, there are highly speculative yet extremely important scientific fields (e.g., these related to the study of climate change) that are fraught with very serious difficulties (e.g., unpredictable weather fluctuations, highly complex trend identification, distinguishing changes due to man's activities vs. natural changes, and physical processes occurring at different scales), which could make it notoriously difficult to even talk about accurate predictions. In exposing this matrix of issues, the one thing we can say with certainty is that an accuracy measure generates *doubt* about a given problem–solution. If one works in an uncertain environment, one's predictions are more valuable if they are accompanied by a degree of doubt, as expressed by an adequate uncertainty measure, rather than blind faith (which is the case of deterministic predictions and religious fundamentalists alike). But this doubt should be seen as a constructive matter that enhances the quality of scientific prediction and understanding. In his unique style Richard Feynman said: "I can live with doubt and uncertainty and not knowing. I have approximate answers and possible beliefs and different degrees of certainty about different things ... It doesn't frighten me." Only individuals who risk nothing in life have absolutely no doubts, and often no imagination as well. It is in this milieu that the concept of an accuracy measure would be considered and appreciated.

7.8 Space–Time Analysis in a Broader Context

We will conclude this chapter with a brief review of space–time estimation within the broader socioanthropological framework discussed in Chapter 1. As part of space-time analysis, estimation's goal is to approximate attribute distributions across the space-time domain. It has also been called space–time prediction (risk analysis, environmental, and information sciences), mapping (earth, atmospheric, and geographical sciences), and imaging (electronic, information, and communication engineering). Major developments go back at least to the early 1960s, and the space–time estimation continued to be an active field of research and development in various scientific disciplines for the last half a century, at least. In general, one can distinguish between the group of "thin" space–time estimation techniques close to the ground as guides to studying and interpreting space–time phenomena, using data and sometimes unexplained correlations; and the group of "thick" techniques, whose tools assure verifiable explanation and science-based prediction of the same phenomena.

Under the circumstances, it is of a broader sociological interest that when mainstream spatial statistics entered the space–time field, mainly in the early 2000s, it dealt with its latecomer status in a manner characteristic of disciplinary esotericism:[27] pretending that space–time analysis simply did not exist prior to the discipline's involvement. This esotericism is rather a function of a thinking mind disciplined by statistics to believe in statistics alone. As such, esotericism overlooks the fundamentals of the sociology of knowledge (e.g., knowers form a community that crosses discipliplinary bounds). Another issue of concern is the increasing focus on marketing and brand naming rather than on conceptual theses and big-picture frameworks (e.g., Section 6.3.1.2). This choice has a considerable effect on the way investigators view their professional careers and contribution to the field. Last but not least, is the discipline's choice to emphasize technicalities, ignoring many other important aspects of the in situ problem. Wittgenstein had an interesting metaphor: "If you shine strong light on one side of a problem, it casts long shadows on the other."

[27] The matter of the discipline's esotericism was discussed in Section 1.8.4.

7.8.1 Space–Time Estimation via Regression, Kriging and Machine Learning

The development of space–time estimation techniques for ordinary S/TRF, known as space–time interpolation, extrapolation and prediction techniques in information sciences, and later as space–time regression techniques in mainstream statistics and Kriging techniques in geostatistics, can be probably traced back to the pioneering work of Petersen and Middleton (1965). Since then, many (conceptual and technical) aspects of space–time statistics have been studied in various disciplines, often with little or no communication between them (e.g., Rouhani and Hall 1989; Christakos 1990a, 1991a, c, 1992; Daley 1991; Handcock and Wallis 1994; Guttorp et al. 1994; Cressie 1994; Goodall and Mardia 1994; Haas, 1995; Bogaert 1996; Cressie and Huang, 1999; Sahu and Mardia 2005b; Gneiting et al. 2007; Guttorp et al. 2007; Lee et al. 2009). Many of these techniques involve some kind of a statistical data fit criterion, assume linear estimators and Gaussian probability laws, are designed to apply to spatially homogeneous and temporally stationary attributes, and express space–time dependence in terms of covariance and variogram functions (Bogaert and Christakos, 1997; Jones and Zhang 1997; Kyriakidis and Journel 1999; de Iaco et al. 2005).

Since space-time analysis has been developed in different disciplines over specific periods of time, one cannot plausibly assume universal understanding and assent among all these disciplines (e.g., during the period early 1930s-middle 1960s, the same mathematical model was known in different scientific disciplines as Wiener-Kolmogorov estimation, objective analysis, regression, and geostatistical kriging). This makes space-time analysis a subject of interest to socioculture (agent's understanding, creating and acting as a function of the disciplinary surroundings) and social constructivism (space-time analysis and the knowledge it generates depending on disciplinary norms and values). Let us briefly review the development of space-time analysis in different fields. Several statistical studies of environmental pollution and human exposure systems are based on a combination of spatial and temporal attribute elements, together with some sort of deseasonalization, time series modeling, statistical regression, splines, or Bayesian analysis (Haslett and Raftery 1989; Li et al. 1999; Sahu et al. 2006; Gryparis et al. 2007; Yanosky et al. 2009; Sahu and Nicolis 2009). These techniques are useful but must be implemented with care, because they can lead to considerable loss of information, especially when it is not known a priori how separate space–time correlations are interconnected. Also, among the different regularities emerging from the dataset it is not always clear which one actually characterizes the underlying physical mechanisms, and whether the spatial or the temporal correlation component of the phenomenon is the dominant one. Often the techniques rely on a limited spatial platform, on the top of which a set of time series is added. The attribute representation produced by the spatial analysis component is static – it serves as a framework whose stability acts as a crude prototype for the more systematic time series analysis that follows. The situation may prove awkward, since it is based on an uneven and rather artificial decomposition of the phenomenon, and often lacks a satisfactory assessment of the attribute distribution in terms of composite space–-time dependence.

In some other cases, the exposure data analysis is characterized by its passive acceptance of strident contradiction. The goal of Peng and Bell (2010), e.g., is to study the effect of pollutant exposure on health but, at the same time, for computational convenience it is presupposed that the health outcome-pollutant exposure relationship is weak. Also, the frequently serious scale effect is ignored (the space–time variation and average pollution at the scale of the county are taken to be the same as those at a much larger scale that includes several counties). Mather et al. (2004) proposed statistical tools to link environmental hazards and exposures to health outcomes. In the study by Bell et al. (2007) the particulate matter mixture varies both geographically and seasonally, and the degree of spatial and temporal variability differs by chemical component. Liu et al. (2009) develop a generalized additive model (GAM) to study pollutant variability using different information sources. What many of these recent works have in common is their rather arbitrary separation of spatial and temporal variations, and their surprising neglect of significant developments in the field.

The hierarchical Bayes models have been used with increasing frequency in the study of space–time phenomena (Le et al. 1997; Le and Zidek 2006). These models are based on a scheme that adds technical flexibility to Bayesian analysis by progressively introducing additional sets of new parameters.[28] In more technical terms, instead of the conventional priors, one may use priors that themselves depend on other parameters not included in the likelihood. These new parameters will in turn require priors, which themselves may depend on a set of new parameters, and so on. Each time, additional assumptions have to be used concerning the distribution of the new parameters, and the process eventually terminates when new sets of parameters are no longer introduced. The above is a technical scheme that involves an arbitrary set of convenient parameters and ad hoc assumptions, in which case a number of issues emerge concerning the underlying logic and the physical substance of the method. *Inter alia*, the scheme threatens to topple the precarious balance between prediction and confirmation by presuming to evaluate the merits of any given feature of the in situ situation on some technical ground other than its own.

Spatiotemporal prediction (estimation) of generalized S/TRF, including composite space–time Kriging as a special case, were also studied to a considerable depth (Christakos 1990a, 1991a, c, 1992); and many applications of the theory in the study of heterogeneous attributes (i.e., with mixed spatially nonhomogeneous and temporally nonstationary patterns) are discussed in the literature. As was pointed out in Pang et al. (2009), the generalized S/TRF approach (which combines heterogeneous space–time dependence models with generalized spatiotemporal air pollution mapping) was used in a number of environmental pollution studies of the 1990s but received little attention at the time (Christakos and Bogaert 1996; Christakos and

[28] Which is why the model was given the characterization of "parametromaniac."

Raghu 1996; Vyas and Christakos 1997; Christakos and Vyas 1998; Christakos and Kolovos 1999). The analysis shares some of the technical difficulties of space–time regression mentioned earlier, although it improves considerably when the generalized operators are properly linked to the physical basis of the phenomenon under study (Section 5.8.2), which means that there is plenty of room for improvement, on both theoretical and interpretive grounds. From a theoretical viewpoint, one of the issues that deserve to be examined in more depth is how the Pythagoreanism (natural kinds in science are those of mathematics) of the operators can be combined with the Aristotelianism (natural kinds in science are those of the physical world) of most KBs. Is it possible that by applying a differential or other form of operator on the original empirical model of an attribute, the derived equations provide new information about the attribute itself? This is not unusual in sciences. One of the most famous examples is James Clerk Maxwell's discovery of his celebrated equations of electromagnetism by applying differential operators on the experimental laws of Ampere, Faraday, and Coulomb. In recent years, generalized spatiotemporal analysis is gradually rediscovered and used in the study of pollution and human exposure phenomena (e.g., Smith et al. 2003). Such developments should be probably seen in the light of evidence that the theory of simple ideas is under considerable suspicion nowadays, and the consequences of this suspicion should have a significant effect on the future of scientific inquiry.

Some of the above techniques have been recently considered in the *machine learning* (ML) framework. ML is a field that is concerned with the question of how to construct algorithms that automatically improve with experience. There is a large variety of machine learning algorithms (MLA; e.g., Cherkassky and Mulier, 1998). MLAs, have been used with considerable success in the solution of certain types of technical problems, such as speech recognition and computer vision; but their implementation in the space-time analysis of physical systems is still at its early phases. Among the pioneers in the field of ML-based spatial data analysis is the group of Mikhail Kanevski (Kanevski et al., 2004). This group has developed an interesting extension of ML in the geographical domain that involves geostatistics techniques and can be used for spatial estimation and mapping purposes. There is considerable room for improvement here. The underlying methodology basically emphasizes syntactic reasoning at the expense of semantic reasoning. For example, the generated maps are coherent under a certain set of rules concerning their derivation and use; but they may not be coherent under an appropriate set of meanings.

7.8.2 Space–Time Estimation as Knowledge Synthesis

According to the broad knowledge synthesis perspective, space–time analysis must be grasped as a gestalt,[29] recognizing composite space–time variation as

[29] An arrangement of entities so unified as a whole that it cannot be described and understood merely as a sum of its parts.

inherently dynamic that moves across the distinction of space versus time. This critical perspective is especially helpful when confronting phenomena with complex yet physically interconnected distributions about which very different data sources are available. Space–time knowledge synthesis includes techniques like BME and GBME, among others (Serre et al. 2001, 2003a; Kolovos et al. 2002; Papantonopoulos and Modis 2006; Law et al. 2006; Yu et al. 2007a; 2009; Yu and Wang 2010; and references therein). A basic feature of the methodology underlying these techniques is that a space-time prediction is generated by the dynamic (i.e., ever-changing) and balanced synthesis of what was known before about the phenomenon (core knowledge) and the additional understanding gained by new case-specific data.

According to Godel's theorem, in order to show that a system is internally consistent (it functions without any contradictions) one cannot rely only on entities (theorems, axioms, data etc.) of this system, but needs to resort to entities external to the system. Similarly, in many cases one system of knowledge (or discipline) does not suffice to solve in situ problems, but needs to be combined with several other knowledge domains (scientific, social, environmental etc.) that originally were considered unrelated. In light of these facts, knowledge synthesis can have a significant sociological impact since it improves communication between investigators from different disciplines, and knowers form communities that cross disciplinary bounds. An IPS investigator searches for substantive links, interdependencies and mutual influences among distinct knowledge domains, and seeks to establish a meaningful synthesis of all the above. A central consideration of knowledge synthesis is the way modern scientists have successfully replaced naturalism with an anthropocentric perspective in applying mathematics in real-world problem-solving (Section 1.9.1.1). The knowledge synthesis techniques blend core knowledge bases, empirical evidence, and multisourced system uncertainty. They also involve theoretical models of considerable generality, e.g., non-Gaussian probability laws and nonlinear predictors are automatically incorporated, the complete PDF is obtained at each space–time point of interest, and they do not experience the logical contradiction or internal consistency problems of the PDD methods[30] (Bogaert 2002, 2004). By incorporating multiple-point statistics and accounting for support and scale effects, knowledge synthesis may further improve science-based spatiotemporal analysis. Also, many space–time regression and Kriging techniques can be derived as special cases of the knowledge synthesis approach. It is noteworthy that MLA-based space-time analysis of physical systems can be considered within a knowledge synthesis framework. This approach provides a balanced synthesis of both modes of reasoning (syntactic and semantic), which complement each other in a meaningful and flexible manner. These are worth-noticing features of the knowledge synthesis approach which yet have not been exploited to their full potential.

Last but not least, the knowledge synthesis approach to integrative problem-solving encourages the active participation of theorists in practical in situ IPS

[30] See, also, Section 9.4.

matters, fully experiencing the problem's environment and the role of other participating scientists within it. Undoubtedly, there are several reasons why theorists should not limit themselves to purely conceptual considerations and abstract constructs. An obvious reason is that in this way the theorists improve their own comprehension of the real-world situation and gain valuable insight from their interaction with investigators in different disciplines. Another reason is that almost any theorist can describe incidents in which their work has been grossly misrepresented by practitioners. Yet another reason is that theorists do not want to give the false impression that they resemble the eunuchs of a harem who know how it is done, they have seen it done every day, yet they are unable to do it themselves. As a matter of fact, it is not unusual that theorists turn out to be better in situ practitioners than expert practitioners themselves, if nothing else because they have a much deeper understanding of the concepts and technical tools they use.

7.8.3 Afflatus Divinus[31]

If earth is another planet's hell, this may be the explanation why many of the above facts concerning spatioremporal analysis are often ignored, which, as already noted, is a phenomenon of significant sociopsychologial interest. To call a spade a spade, hypocrisy and distortion are often passing currents under the name of disciplinary loyalty, whereas unquestionable commitment to a specific discipline represents a willful falling away from a thinker's high responsibility to truth and justice. For many scholars, the shadow epistemology characterizing corporate science (Section 1.4) and the education provided by the PCU model (Section 1.5) are to be blamed, to a considerable extent, for this sad state of affairs.

Of considerable interest to the theory of sociological mindfulness is that many people persist, even in the face of over-whelming evidence, in reading their own values and interests into what ought to be an objective assessment of scientific developments. A recent review of space–time statistics is enlightening in this respect. The readers are informed that, the authors of the review and those close to them are among the very early authors who [in the middle 1990s] obtained statistical models for spatio-temporal data" (Sahu and Mardia 2005a: 71). This is hardly an accurate claim or one that even the discipline's deepest esotericism could sustain, in view of the fact that systematic work in space–time statistics goes at least as far back as the middle 1960s, with several developments in the following 30 years and beyond. Given the circumstances, it comes as no surprise that the review conveniently omits a host of space–time statistics publications that preceded the works it mentions by several years. On a relevant note, corporate geostatistics would benefit significantly by familiarizing itself with important developments in the study of real-world interdisciplinary systems in a way that not only describes,

[31] Divine inspiration.

but it explains and creates too. At a minimum, searching the space-time analysis literature would help the geostatistics practitioners avoid making unfounded claims of some sort of bias. It is common knowledge that corporate geostatistics has mostly failed to generate surer and firmer knowledge about the things it studies, and to propose theoretical frameworks that would explain the relationship between geostatistics and the increasing complex real-world. Instead, corporate geostatistic is characterized by conceptual repetition, in which platitudes frequently come up against truisms, and the development of banal software. Nevertheless, geostatistics Illuminati apparently have convinced themselves that *in regione caecorum rex est luscus*,[32] which is why they are on a mission to enlighten those practitioners who are willing to listen that nothing significant has been done so far in the field of space–time modeling of heterogeneous data. Accordingly, the field of space–time analysis desperately awaits the Illuminati's *afflatus divinus* as its last hope for advancement. Thousands of years ago, Lao Tzu (Section 1.1.2.4) taught that, "To know what you do not know is the best. To pretend to know when you do not know is disease." When it comes to corporate science and institutionalized research the words of the wise man fall in deaf ears.

[32] In the land of the blind the one-eyed man is king.

Chapter 8
On Model-Choice

Life is the sum of all your choices.

A. Camus

8.1 Living in Plato's Cave

In the course of integrative problem solving (IPS), in the broad sense, investigators encounter a plethora of models representing aspects of the real-world that seem relevant to the solution of the problem at hand. These models (mathematical or otherwise, analytical or computational) are characterized by a varying degree of complexity and fundamentality. One cannot be perfectly sure which model is the best one for the situation, in the same way that one cannot *know* absolutely in a metaphysical sense. This was, in fact, Plato's philosophical perspective: ultimate reality (or pure *forms*; see Section 2.2.4) is too perfect to be knowable by humans. The most humans can do is to look at the shadows cast by the forms on the walls of the cave[1] and make an attempt to infer the forms in terms of their shadows. In a similar way, the argument goes, an investigator can select the best model of reality by carefully examining the available evidence, using critical thinking and, on occasion, creative reasoning. There is no guarantee, though, that this will be the true model of ultimate reality.

8.1.1 *Conditions of Model-Choice, the Blind Prophet, and Slavoj Zizek*

Being a key component of in situ IPS, model-choice is a complex affair that, more often than not, cannot be based on textbook definitions, pseudo-practical doctrines, and "bottom-line" recipes. What is certain is that, at any stage of model-choice there

[1] *Plato's cave* is probably the most famous cave in the history of philosophical thought.

G. Christakos, *Integrative Problem-Solving in a Time of Decadence*,
DOI 10.1007/978-90-481-9890-0_8,

is a corpus of questions and issues that are worth asking and answering or resolving. Accordingly, a reasonable choice of a model in a real-world situation depends on the initial conditions and the evolving characteristics of the "problem–agent" association, which include:

(a) Agent's *epistemic* situation
(b) *Evidence* concerning the previous performance of the models
(c) Model *complexity* in association with the agent's level of sophistication
(d) Availability of good *quality data* (for model parameter estimation, etc.)
(e) *Intended use* of the model
(f) Knowable and unknowable sources of *risk*
(g) Model *types*
(h) Agent's *creativity*

As far as Item *a* is concerned, the investigator's epistemic situation (understanding of the underlying physics, logical constraints, and social characteristics) can play a major role in model-choice. As we saw in Section 7.3.4, e.g., when the investigator needs to choose between different models of probability conditionals, the choice depends (*inter alia*) on the importance the investigator wants the model to assign to the core versus site-specific KBs (some models assigns more weight to core KB, whereas some others to site-specific KB). This does not mean that perfect cognition conditions can be guaranteed in real-world situations. Instead, it is always possible that one is deceived by a KB that looks correct at the moment, but turns out to be wrong later. There are cases in which political, scientific or corporate elites manipulated data to serve their agenda (several examples are discussed in the book). This is especially true during Decadent times when all the vital knowledge is controlled by the powers that be and the people's rights are in question (Section 1.4). One of the most painful periods was that following the 9/11 disaster when the U.S. government seriously restricted access to important information and limited people's freedoms. Richard K.L. Collins and David M. Skover (2009: xxii) paint a grim picture: "In America, the dissenter is effectively silenced, and a citizenry that should jealously safeguard its constitutional liberties is lulled into passivity, by an oblivious commercial and entertainment culture." Concerning Item *b*, a primary concern of problem solvers is to collect information about the previous performance of a model in real-world situations similar to those associated with the problem at hand. For example, if the evidence in its favor is overwhelming, the model will be provisionally accepted, since it would be foolish to reject it at this stage. Of course, certain issues of subjectivity may arise, such as how similar the previous situations are with the current problem.[2]

[2] One wonders what the postmodern perspective would be concerning Item *b*. As noted earlier, by poignantly ignoring knowledge obtained in the past, the postmodern world has turned into sort of a black hole.

Item *c* is a major issue in scientific modeling. Many studies argue that complex models offer a better representation of uncertainty and more accurate predictions for cleaner data. On the other hand, other studies suggest that simpler yet physically meaningful models may yield more accurate predictions in case of rather noisy data (Sober 2008). Under certain circumstances, a number of studies argue, the models can be more accurate than the data used to build them, because they are capable of amplifying hidden patterns and ignoring noise (Gauch 1993). No doubt, as noted in previous chapters, there is a strong anthropocentric element in the agent–model interaction at work. Generally, one may say that the more sophisticated the investigator is, the more adequate the implementation of the model. It is also true that more often than not users treat models as "black-boxes." In these cases, the real issue is not the model's potential inadequacy to represent the phenomenon, but rather the user's own inability to implement the model properly. Form (model) cannot fool substance (Nature), and those investigators who attempt this trick almost certainly fool only themselves, which is yet another phenomenon with considerable social and epistemological dimensions. There is a general rule at work linked to Item *d*: the application of a model is always limited by the current ability to measure the relevant model parameters. It is a common secret that often there is a significant difference between the parameters of the conceptual model and the parameters of the measurement model used in the in situ implementation of the conceptual model. The real issue is not how close the measurements agree with the model predictions, but rather whether the discrepancy between the measurements and the model predictions is greater than the discrepancy that would be expected given the existing measurement reliability.

Concerning Item *e*, surely there is no reason to use a sophisticated model when the problem at hand is rather elementary. On the other hand, one cannot rely on a simplistic model to study a complex and multifaceted phenomenon ("one cannot cure cancer with an aspirin," skeptics say). The interplay between complex and simple models is a dynamic process during which the two classes of models are engaged in a dialectic whose inevitable friction can generate new versions of each. A familiar example is the case of linear models. For tractability's sake one selects a model that is based on simplifying assumptions about reality involving linear terms. This simple model may be appropriate at a local scale (linearity assumptions work under static conditions). But if the problem circumstances change, and no longer refer to the linear part of the curve, the simple model does a poor job of describing the phenomenon, in which case a more complex model needs to be used at this stage of problem solution. The simple model still has value, but using it correctly requires an awareness that it does not hold globally.

Concerning Item *f*, it has been true since the dawn of times that choices involve *risks*, which sometimes are very serious, as Tiresias (*Τειρεσίας*) the blind prophet of ancient Thebes could testify. Tiresias had the unique experience of having lived for a period of time as a woman before he became a man again. Because of his unique expertise, Tiresias was asked by Zeus and Hera, the chief Greek deities, to settle a dispute between them as to which sex got most pleasure out of love. When he responded that it was the female, Hera was displeased with his choice and she blinded him. Since then, every time one makes a choice one takes a certain risk. This is especially true when the choice is made among models (physical, biological, social, or financial) the construction of which, the degree to which they represent reality, and the factors that can potentially affect their performance are unknown. For example, largely responsible for the worldwide economic catastrophe of 2008 was the choice of the financial models the markets were using (Taleb 2008b; Salmon 2009). The world being what it is, often the wrong choices affect other people more than they affect those who made the choices in the first place. Which is why, referring to the same catastrophe, Slavoj Zizek (2009: 16) observed that,

> We do indeed live in a society of risky choices, but one in which some do the choosing while others do the risking.

Item *g* brings to the readers' attention the fact that the models among which one has to choose may be of fundamentally different structure. They may be *substantive* models that are based on scientific laws (Table 1.1). Or, they may be models that are merely *technical* (e.g., time series, polynomial, and spline functions). Substantive models are constrained by the fact that they are based on certain hypotheses about the underlying natural mechanisms (content-dependent models). Hence, their flexibility is restricted and often they may not offer a perfect fit to the old and new data. Technical models, on the other hand, have almost infinite flexibility but very limited physical informativeness (content-independent models). For example, by including more parameters in a polynomial model that can be tuned to agree with old and new data, one learns little of substance concerning the in situ phenomenon. Last but not least, Item *h* is a very important yet not fully appreciated component of model-choice. *Creative* model-choice is a way to express what it is about choice that eludes rational representation. As such, it is capable of producing things that are new and valuable at the same time. When a fresh and previously untried way of looking at a problem is required, creative model-choice may be the only way to deal with the situation. We will revisit creative thinking and its potential effects in Chapter 9.

8.1.2 Explanation Versus Fitness

It must be already apparent that model-choice is a multifold affair (multidiscipline, multidatabase, multiobjective, and multithematic) that cannot be packaged in a readily applicable form (recipes, "black box" instructions, and the like). The class of *substantive* methods can integrate in the model-choice process various kinds of laws—physical, biological, economic, etc. (Black and Scholes 1973; Bower and Hilgard 1981; Bothamley 2002; Lide 2009).[3] Another class

[3] More details are given in Section 8.3.2.

of methods seeks to fit to the data the *technical* models mentioned above (these models are primarily empirical, and often there is no scientific theory relating them to the actual mechanisms of the phenomenon that generates the data). Many of the technical model-choice methods, either implicitly or explicitly, choose a trade-off between data *goodness-of-fit* and the model *complexity*. This is the case, for example with the minimum description length and statistical regression methods (Motulsky and Christopoulos 2004; Grünwald et al. 2005).

The above considerations highlight some additional differences between model-choice in the technical sense and model-choice in the substantive sense. Indeed, there is a fundamental distinction between the doctrine "The more facts the model *explains*, the better it is" [D1] and the doctrine "The more data the model *fits*, the better it is" [D2]. The doctrine D1 is associated with substantive model-choice, since it is content dependent and it may be involved in the testing of a deep and general scientific model or theory (including high-level theories such as Newton's theory of gravitation or Darwin's theory of evolution; physical models of various kinds and levels of fundamentality; as well as mechanistic models, like the Black-Scholes model of option pricing). The key notion in substantive model-choice is *explanatory power*: for example, Einstein's theory was better than Newton's because it explained more phenomena (Misner et al. 1973; Taylor and Wheeler 1992). The doctrine D2, on the other hand, is linked to technical model-choice (Ripley 1996; Spiegelhalter et al. 2002; Burnham and Anderson 2002). It is content independent and essentially processes numerical attribute values (e.g., numerical model estimates versus measured values). Many human exposure and epidemiology studies rely on complex technical (statistical) models, but lack substantive justification and explanatory power (e.g., Briggs et al. 1997; Gryparis et al. 2007; Martin and Roberts 2008). These models ignore physical space–time interactions, and make convenient yet simplistic assumptions, such as the additivity of all relevant effects and the belief that simplicity automatically brings truth (Yanosky et al. 2008, 2009; Katsouyanni et al. 2009). In more general terms, these models fail not only because of technical inadequacy, but because they represent an exercise of reason that ignores the physical conditions enabling reason's rational reflection on the in situ phenomenon.

8.2 Issues of Concern

This subsection focuses on a number of key model-choice concerns that are sometimes neglected, with potentially severe consequences in risk assessment and decision making. In many cases, there are not effective ways to fully address these concerns. Nevertheless, one needs to be aware of their existence, and be prepared to deal with them in a satisfactory manner.

8.2.1 Nature of Candidate Models and Balzac's Wild Ass's Skin

As we saw in Section 8.1, the fact that the models among which one must choose have a fundamentally different nature can affect the model-choice process. One should be cautious, since the same data sets may be linked to both scientific and technical models, but in different ways: the main goal of technical modeling is to fit data values in some sense of "technical optimality," but with no concern about the physical origin and meaning of these values, or about the testing and refinement of the modeling-reality association. This sort of modeling favors the use of a plethora of ad hoc combinations of statistical hypotheses and schemes to represent the phenomenon under in situ conditions. More often than not, such studies can lead to internal inconsistencies and the wrong conclusions (Section 9.4). One gets the impression that every time yet another ad hoc technical model or assumption is introduced to fit the data, contemplative and analytical thought thin out faster than the wild ass's skin in Balzac's homonymous novel, which was shrinking every time its owner made a thoughtless wish (Balzac 1901).

Whatever the in situ case might be, their content-free character is one of the reasons that purely technical models can offer good fit to the existing data. But this comes at a price, since it turns out that the content-free models have serious drawbacks: While their arbitrary complexity can offer a perfect fit to the given data set, when these models make predictions the results are often very poor. This is related, of course, to Hume's problem of induction (Section 2.2.9). Also relevant is Francis Crick's warning:

> Any model that can account for all of the facts is wrong, because some of the facts are always wrong.

Another issue of potential concern is that many statistical models are often *nested*; e.g., the mathematical conditions of the popular likelihood ratio tests are based on the assumption of nested models (Burnham and Anderson 2002). In this case, certain questions arise that pertain to model-choice. Assume that one needs to choose between two models: M_1 and M_2. If the simpler model M_1 is nested in the complex model M_2, then, if M_2 is false, so is M_1. In this case, the logical relations between the models should be investigated and become part of the model-choice process. Scientific models, on the other hand, are built on the basis of physical knowledge and bold hypotheses, and seek to establish a dialectic between themselves and the data (in an attempt to explain the data and gain a deeper understanding of the underlying mechanisms) than simply fit the data values. Hence, as noted earlier, scientific models sometimes do not offer a perfect fit to the data. But this does not seem to bother scientists, since the data themselves include considerable amounts of uncertainty and, also, the scientific models are intended to be idealizations of reality (focusing on its key aspects), and not perfect representations of it. In this case, one needs epistemically meaningful criteria to choose among the models (criteria of predictability, coherency, and explanatory power). But let us first examine in more detail the data-fitting techniques.

8.2.2 Optimal Data Fitting

A popular doctrine of technical model-choice is that a model should be chosen that offers the best *data fit*, in some technical sense. Naturally, there are different versions of this data-driven doctrine with varying levels of sophistication. One can find in the literature serious concerns about the theoretical rigor and in situ validity of the "brute-force" implementation of the best data fit doctrine (some of these concerns were discussed in previous sections). Therefore, healthy skepticism is always useful in science: while it should be taken seriously into consideration, the optimal data fit doctrine may be not adequate by itself.

Interestingly, Crick's comment mentioned in the previous section is directly related to the following situation. Vladimir Cherkassky and Filip Mulier performed an interesting numerical model comparison (Fig. 8.1; Cherkassky and Mulier 1998: 43). The actual phenomenon was described by $y = x^2$, and the available data included some noise, so that $d = y + noise$ (this is the site-specific KB, in this case). The authors assumed that it was known that the actual phenomenon obeyed a second-order polynomial law (which is the core KB), but its coefficients were unknown. Accordingly, two candidate models were compared:

$$\left.\begin{array}{l}\text{Model 1}: y = ax \\ \text{Model 2}: y = bx^2 + c\end{array}\right\} \quad (8.1)$$

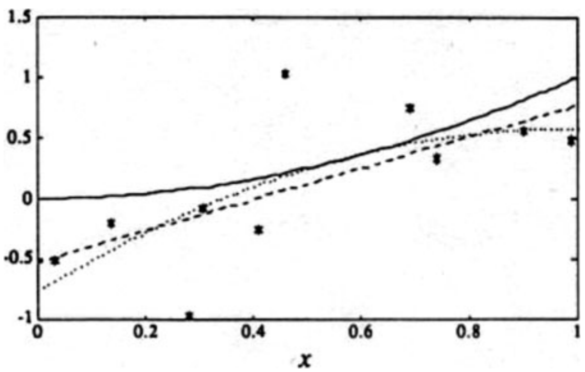


Fig. 8.1 Data denoted by *asterisks*; actual phenomenon by solid line; Model 1 by *dashed* line, and Model 2 by *dotted* line (Reproduced with permission from Cherkassky and Mulier 1998)

where the coefficients *a*, *b* and *c* were calculated from the available (noisy) data. The first thing one notices in Fig. 8.1 is that the specific data set offered a poor representation of the actual phenomenon. Nevertheless, the authors calculated the fits of the two models to the data, and they found that Model 1 had a smaller mean squared error (MSE = 0.0596 units) than Model 2 (0.0845 units). Based on the best data-fit doctrine, Model 1 was considered a better choice. To justify this choice the authors maintained that, "limiting model complexity is more important than using true assumptions" (Cherkassky and Mulier 1998: 43). This is yet another PDD claim that seeks to diminish the value of truth.[4] On the contrary, many scholars affirm with Bruce G. Charlton: "Real science must be an arena where truth is the rule; or else the activity simply stops being science and becomes something else: Zombie science" (Charlton 2009: 633). Those who worship either PDD or minimal model complexity should always keep in mind that blurry data are more likely to be consistent with mathematical simplicity. But simplicity does not automatically bring truth. In fact, as can be seen in Fig. 8.1, Model 2 fits better the actual phenomenon than Model 1 (the latter is approximately 40% of the time closer to the actual phenomenon, whereas the former about 60% of the time). From this, it is concluded that the selection of Model 2 on the basis of core knowledge would be a better choice (it is closer to the actual phenomenon), even if Model 2 is more complex and does not offer as good a data fit as Model 1 (after all, the data offer a poor representation of the actual phenomenon). This result should not come as a surprise even to the strongest proponents of PDD analysis, since both theoretical arguments and empirical evidence suggest that simpler models often do not lead to greater accuracy (Domingos 1998, 1999). Another point demonstrated in the above example is how misleading a data set can be about the actual phenomenon: the noisy data set in Fig. 8.1 led to the generation of models that missed much of the structure of the actual phenomenon. The inconsistency between core knowledge and noisy data offers clear evidence concerning poor data quality.

In sum, this example shows that a model-choice criterion depends decisively on the investigator's presuppositions, background, and worldview. An investigator who favors the PDD perspective (e.g., an empiricists who seeks to learn only from data) would rather prefer Model 1, since it fits the data better than Model 2 (even Model 1 it is an inadequate representation of true knowledge).[5] On the other hand, an agent who is concerned about the physical theory behind the data (e.g., a realist) would chose Model 2, since it is closer to theory (even if its data fit is not as good as that of Model 1). Another important point I would like to stress before leaving this section is that the PDD mindset (i.e., selecting a model solely on comparison with data) is methodologically rather naïve, since it neglects the fact that there are several *extra-data* factors that can ultimately affect the model-choice. One such extra-data factor is circumstantial knowledge about the candidate models (e.g., if the investigator knows that a specific model has been developed by the

[4] See, also, Section 9.4.1.

[5] This perspective is closely linked to Occam's razor, Section 8.2.3 that follows.

world's expert in the field or that it has been extensively tested in situ, it is natural that the investigator will favor this model against less tested models or models developed by relatively unknown scientists). Another significant extra-data factor is that the evaluation of a model depends on the existence of other models: whether or not a specific model is selected depends on other models that emerge during the model-choice process (e.g., a model that was considered the best choice at some point may not be so when other models become available). Let me bring the discussion to a close with a historical fact. Even as back as in the late 16th–early 17th century, the great Galileo Galilei did not base his scientific arguments directly upon data of any kind. To quote Moti Ben-Ari (2005: 3),

> When Galileo presented his results, he rarely referred to experimental results and never provided appendices full of tables and graphs.

8.2.3 From Occam's Razor To Rovespiere's Gilotine

In an apparent effort to carry philosophical weight, technical model-choice methods have made several attempts to incorporate in their description some version of Occam's razor[6]: one should always select the *simplest* model that fits the data. In computer science, e.g., the minimum description length method of model-choice is viewed as a form of Occam's razor, in the sense that a model should be chosen that minimizes the sum of the length of the model and the length of the data encoded using the model (Grünwald et al. 2005). Nevertheless, some critics have argued that the implementation of Occam's razor is not appropriate in this case, since it favors the simplest models to represent real-world situations that are actually arbitrarily complex (Webb 1996).

In Bayesian statistics, noteworthy attempts to blend the ideas of Occam and Bayes include the works of Harold Jeffreys, William H. Jefferys, and James O. Berger. According to Jeffreys (1939: 47), people should choose their prior probabilities so that they favor the simpler model that fits the data best (J1). There is no consideration, at the moment, of either data uncertainty or the logical validity of the premise J1. In fact, Jeffreys's thinking became more confusing when he later argued that if one makes some reasonable[7] assumptions, the PDD model selection can be justified by choosing the model that has greater posterior probability on the data even if the prior probability does not favor this model (J2). Some obvious concerns were raised about the logical consistency of J1 and J2, and their consequences in real-world model-choice. Nevertheless, Jefferys and Berger believe that "this result [J2] was a form of Ockham's razor," and that the razor depends on the probabilistic modeling of the effect of the model on the data (Jefferys and Berger 1991: 2). Apparently satisfied

[6] Also known as Ockham's razor.

[7] Many authors believe that the exact meaning of the term "reasonable" was not made sufficiently clear by Harold Jeffreys.

with their interpretation, they extended Jeffreys' ideas and proposed a Bayesian approach that "can be seen to yield a quantified Occam's razor, i.e., a theorem establishing that a simpler model is more likely to be true than a complicated model when both models are reasonably compatible with the data" (Berger and Jefferys 1991: 3). This Bayesian version of Occam's razor is not consistent with the *modus agendi* of scientific model-choice in the real world. The assumption that "one of the models under consideration is true" (Gregory 2005: 46) profoundly contradicts the essence of scientific inquiry. Among other things, the Occam-Bayes assumption neglects important extra-data factors, such as circumstantial knowledge and the possibility that better models could emerge during the model-choice process, which is a characteristic of PDD methods, in general (see, also, Section 8.2.2). As a matter of fact, so much knowledge is neglected that what was before Occam's razor has now become *Rovespiere's gilotine*. Also, in visual perception research the key evolutionary question is where the probabilities (Bayes) or complexities (Occam) come from, and thereby, which goes deeper than the statistical question of how well models fit data (van der Helm 2000). Eric V. Linder and Ramon Miquel (2009: 2315) warned us that, "When statistical techniques such as 'model selection' or 'integrated survey optimization' blindly apply Occam's Razor, this can lead to painful results." Furthermore, Wences P. Gouveia and John A. Scales (1996) described a seismic field-data inversion study in which the results obtained by the Bayesian and the Occam models differed significantly. While for estimation purposes the prior probability model is selected for convenience with the assurance that in moderately large samples the effect of the prior model becomes irrelevant, this is not so in scientific model-choice, where the selection of the prior model should be adequately justified, because it can be consequential (Kass and Raftery 1993). The readers can find several examples in physical sciences where different ways of assigning prior probabilities lead to totally different anthropic predictions (e.g., Starkman and Trotta, 2006). Although Occam's razor roughly states that, all other things being equal, the simplest solution is the best choice, it is not clear what is the precise meaning that Berger and Jefferys assign to the crucial phrase "all other things being equal" and to the term "simplest." Directly related to these issues are questions like, what aspects of the models should be evaluated for simplicity? Should simplicity be considered in a pragmatic, semantic, or epistemic sense? Do "other things" include the substantive core knowledge about the in situ problem, and in what way? Can the prior probabilities of the candidate models be determined without making ad hoc assumptions? In the Occam-Bayes theory, does physics or statistics retain a central role in interpreting the data? For a multidisciplinary in situ problem, where different disciplines and thinking modes are involved, what seems the simplest solution to one thinking mode may not seem so to another. In sum, it seems that a "blind date" was arranged between Occam and Bayes. Although they do not know each other, the date organizers seem to believe that they will be able to feel respect and affection for each other. This may be so, but it is also true that Occam and Bayes will need to resolve sharp differences in their respective worldviews.

In light of these considerations, just as in the case of the Cherkassky-Mulier approach (Fig. 8.1), Model 1 would be the choice of the Occam-Bayes approach, as well: Model 1 is the simplest model that offers the best fit to (is most compatible with) the data. No due attention is paid to the possibility that Model 2 represents important aspects of the underlying physical law, which Model 1 fails to do (a thinking mode that is, again, in agreement with the PDD viewpoint). *Horribile dictu*, but what escapes the data- and razor-driven mindsets is that model-choice should satisfy a key requirement: model consistency with both the underlying physics of the situation and the in situ data (taking into account, of course, the uncertainty of these data). This twofold requirement offers strong motivation to develop integrative theories of model-choice.

8.2.4 On Predictability

A popular model-choice perspective is based on the direct use of the *predictability* (or *forecasting*) criterion: the same attributes are predicted (estimated) on the basis of the different models available, and that model is chosen that generates the best predictions. Indeed, many people believe that, "It is far preferable to focus on our real experiences of recorded history and to assess the validity of competing scientific understandings through their performances in forecasting" (Lad 2006: 443).

Although the above approach seems reasonable—most of us have used it in a way or another—it is not based on a problem-free reasoning. Indeed, it can be shown on the basis of comparative analysis (Christakos et al. 2005) that a model M_1 may be better than a model M_2 when predicting a set of model variables, but model M_2 may be better than model M_1 when predicting another set of related model variables, all of which are associated with the same phenomenon. For illustration purposes, consider a rather classical yet instructive example. Models M_1 and M_2 represent the same phenomenon, as follows

$$\left.\begin{array}{l} M_1:\ 2\chi_{1,\boldsymbol{p}} - \chi_{2,\boldsymbol{p}} + \psi_{1,\boldsymbol{p}} = 0 \\ M_2:\ 3\chi_{1,\boldsymbol{p}} - 2\chi_{2,\boldsymbol{p}} + \psi_{2,\boldsymbol{p}} = 0 \end{array}\right\}, \tag{8.2}$$

where the attribute realizations $\chi_{1,\boldsymbol{p}}$ and $\chi_{2,\boldsymbol{p}}$ are associated with one aspect of the phenomenon (say, environmental exposure), whereas the attributes $\psi_{1,\boldsymbol{p}}$ and $\psi_{2,\boldsymbol{p}}$ are linked to another yet relevant aspect of the phenomenon (say, population health effect). Suppose that the correct (perfect measurements) values of the four model attributes are given below,

$$\left.\begin{array}{l} \chi_{1,\boldsymbol{p}} = 0, \chi_{2,\boldsymbol{p}} = 1 \\ \psi_{1,\boldsymbol{p}} = 1, \psi_{2,\boldsymbol{p}} = 2 \end{array}\right\}. \tag{8.3}$$

Let us assume that the two models, unaware of (8.3), make the following predictions of $\chi_{1,\boldsymbol{p}}$ and $\chi_{2,\boldsymbol{p}}$:

$$\left.\begin{array}{ll} Attribute & : \chi_{1,\boldsymbol{p}} \quad \chi_{2,\boldsymbol{p}} \\ M_1 & : 0.15 \quad 1.225 \\ M_2 & : 0.10 \quad 1.0 \end{array}\right\}. \tag{8.4}$$

If an investigator (say, an environmental exposure expert) selects the best model on the basis of the model predictions of $\chi_{1,\boldsymbol{p}}$ and $\chi_{2,\boldsymbol{p}}$ in (8.4), the best model turns out to be M_2:

$$\left.\begin{array}{ll} Attribute & : \chi_{1,\boldsymbol{p}} \quad \chi_{2,\boldsymbol{p}} \\ Truth & : 0.00 \quad 1.0 \\ M_1 & : 0.15 \quad 1.225 \\ M_2 & : 0.10 \quad 1.0 \end{array}\right\} \Rightarrow M_2. \tag{8.5}$$

But, if an investigator (say, a population health expert) chooses to test for the best model on the basis of the corresponding model predictions of $\psi_{1,\boldsymbol{p}}$ and $\psi_{2,\boldsymbol{p}}$, which are obtained from Eq. (8.2) by inserting the $\chi_{1,\boldsymbol{p}}$ and $\chi_{2,\boldsymbol{p}}$ values of Eq. (8.4), the result is that the best model is M_1; i.e.,

$$\left.\begin{array}{ll} Attribute & : \psi_{\boldsymbol{p}_1} \quad \psi_{\boldsymbol{p}_2} \\ Truth & : 1.0 \quad 2.0 \\ M_1 & : 0.925 \quad 2.0 \\ M_2 & : 0.80 \quad 1.7 \end{array}\right\} \Rightarrow M_1. \tag{8.6}$$

Notice that the important issues that this simple example brings to the fore remain valid in more involved in situ situations (Christakos et al. 2005: 58–62). Until a satisfactory response has been obtained to the conceptual and methodological issues raised by the above and similar examples, a large class of model-choice methods based on the quality of the predictions (Ein-Dor and Feldmesser 1987; Burnham and Anderson 2002) should be viewed with some scepticism and used with due caution.

8.3 Ideals of Model-Choice

When facing a model-choice decision, one should be aware of three fundamental yet often neglected facts: (*a*) more often than not, the investigators do not have a sufficient understanding of the uncertainties and risks they are subject to; (*b*) in some cases, although the investigators do not have the faintest idea about the uncertainties and risks incurred, yet they are convinced that they possess a deep comprehension of them; and (*c*) it is not uncommon that in a number of cases (e.g., linked to situations of high political, financial, or health risks) the investigators are uncertain of what their own ideals and values, in fact, are. The implementation of ideals in model-choice requires a careful consideration of the context and content of the in situ situation. To a certain extent, in situ model-choice is guided by the ideals of the investigators involved in the solution of the specific problem and the world perspective of the stakeholders (i.e., those affected by the solution). In a way, these ideals are like Carl Schurz's stars: "You will not succeed in touching them with your hands, but like the seafaring man on the ocean desert of waters, you choose them as your guides, and following them, you reach your destiny."

Since ancient times truth has been the ultimate ideal, yet the search for it was not a naïve undertaking. Quite the contrary, the ancients were aware of the difficulties (uncertainty sources, knowledge reliability, etc.), and they approached the ideal of truth in a realistic manner. A quote by Xenophanes is appropriate at this point:

> The gods did not reveal, from the beginning,
> All things to us, but in the course of time
> Through seeking we may learn and know things better.
> But as for certain truth, no man has known it,
> Nor shall he know it, neither of the gods
> Nor yet of all things of which I speak.
> For even if by chance he were to utter
> The final truth, he would himself not know it:
> For all is but a woven web of guesses.

Below we will consider some more ideals of model-choice associated with different categories of in situ problems.

8.3.1 Contextual Appropriateness

First, we must keep in mind that model-choice is always *contextually appropriate*. In other words, no systematic model-choice procedure exists that applies equally well in all in situ problems. Instead, model-choice is a contextual affair, which implies that the ideals upon which the choice will be based vary according to the predominant features of the problem at hand: the available KBs, the problem-solution goals, and the sociopolitical situation within which the problem emerges.

A key characteristic of contextual appropriateness is *model specification*, i.e., determination of the set of all possible models M_q ($q = 1, 2, ..., w$) pertinent to the particular problem during each phase of the study. Often this set of candidate models is not clearly determined (i.e., the number w of possible models may vary from a problem solver to another, and from a time period to another). The difficulty of model specification is a natural consequence of the limits of the human brain and, the investigator's cognitive condition. For illustration, Table 8.1 describes four major categories of problems encountered in the process of scientific inquiry. For the sake of discussion, Table 8.2 considers a list of possible ideals that apply in

Table 8.1 Possible problem categories

1. Generating space–time attribute predictions
2. Testing scientific hypotheses
3. Explaining the largest number of observed phenomena
4. Making new discoveries

Table 8.2 Possible ideals of problem-solving

(a) High level of certainty (or low level of uncertainty)
(b) Improved predictability (in some sense)
(c) Best support by the available knowledge bases
(d) High level of flexibility
(e) Deeper understanding of the underlying mechanisms
(f) High level of falsifiability

different cases and represent distinct perspectives. Concerning problem Category 1 (Table 8.1), the investigator's priority may be to select the model that satisfies Ideals *a* and *b* (Table 8.2). In the case of Category 2, one would select the model that satisfies primarily Ideal *c*. For Category 3, one may favor a model that focuses on Ideals *d* and *e*. For Category 4, one would prefer the model that satisfies Ideals *e* and *f*. Surely, other category-ideal combinations are possible depending on the situation. All these combinations offer to the investigator a valuable sense of *purpose* and *direction* in the general milieu of model-choice.

8.3.2 *Quantitative Representations*

To gain further insight in quantitative model-choice, let M_q ($q = 1, ..., w$) denote the set of candidate models associated with the space–time variation of the attributes of interest. The M_q may include substantive and/or technical kind of models, as described before. Each one of the candidate models offers a different level of fit to the possible combinations of problem categories and problem-solving ideals (Tables 8.1 and 8.2). Certain matters of significance related to the in situ choice of the most appropriate model (or combination of models) are discussed below. Before setting out on these matters, let me remind the readers that unlike the PDD paradigm in which the M_q are ad hoc statistics models (e.g., Ratmann et al. 2009), in the present section the M_q represent real-world models (physical, biological, ecological, etc.). The former are merely useful data summaries, whereas the latter are fundamental descriptions of the data based on physical principles.

8.3.2.1 Integrative Model-Choice

Far from being merely concise ways of data representations, the coefficients and auxiliary parameters of the M_q have deep physical interpretations. Having said that, in the IPS setting the integrative model-choice approach may be represented as follows:

$$\left.\begin{array}{l} M_q \\ q = 1, \ldots, w \end{array}\right\} \xrightarrow{G} f_{G_q} \xrightarrow{S} f_{K_q}, \tag{8.7}$$

where the core KB G_q includes the candidate model M_q. For simplicity in notation, let $G_q = M_q$ (although G_q may generally include other core knowledge sources, in addition to M_q). The process (8.7) provides the integrated probability distributions f_{K_q} for each one of the candidate models M_q at a certain phase of the process (8.7); i.e., some of them may change or be replaced at a later phase. Each f_{K_q} incorporates the corresponding KBs (core and specificatory), $K_q = M_q \cup S_q$. In this way, (8.7) allows the investigator to gain a better understanding of each model's relation to the problem at hand (whether the M_q have meaning in the problem context, under what conditions, etc.); to determine how each M_q should be integrated with the site-specific data set S_q (e.g., should SC, MC, or EC adaptation be used; Sections 6.2.2 and 7.3.4.4); and to derive the various f_{K_q} with the desired characteristics (corresponding, say, to the M_q with the maximum explanatory power and/or accounting for the largest S_q size possible). The model-choice process (8.7) allows considerable flexibility. The investigator can repeat a component of the process (8.7), depending on the feedback gained. Different model (M_q)-data (S_q) combinations may be considered. Since each M_q may include variables that not all refer to the same system, the model-choice will depend on those M_q variables that the investigator favors. Moreover, each model M_q can be compared with the other candidate models at various levels, including data fits, extra-data factors, and model-data coordination. In fact, the choice of a specified model M_q may be affected by evidence concerning other models $M_{q'}$ ($q' \neq q$); some of these models may be interdisciplinary, which adds context and depth to the model-choice arguments.

The integrative process (8.7) allows considerable reflection, which is an internal process of IPS thinking that creates awareness and knowledge building. This is essentially the ability or disposition to reflect on an issue and resist reporting the first response that comes to mind, which helps the investigator formulate a sound methodology of model-choice. Given f_{K_q} in the last phase of the process (8.7), the model-choice ideals can be expressed in a suitable quantitative form. In some cases, the Ideal *a* (Table 8.2) corresponds to the maximization of the specified attribute probability, $M_q : \max_{M_q} P_{M_q}[\chi_p \backslash S_q]$; or equivalently, the minimization of the associated uncertainty, $M_q : \min_{M_q} U_{M_q}[\chi_{\boldsymbol{p}} \backslash S_q]$. In some other cases, the Ideal *b* (Table 8.2) is linked to the maximization of the conditional attribute expectation, $M_q : \max_{M_q} \overline{X_p}|_{M_q \cup S_q}$. Moreover, one may decide to select the model that maximizes the accuracy of key (social, economic, policy, etc.) functions. Furthermore, using Table 6.8, one can measure how much the S_q improves the problem solutions generated by M_q in terms of the corresponding CDIs, i.e.,

$$\Phi_{S_q} = P_{M_q}[\chi_{\boldsymbol{p}j} \backslash S_q] - P_{M_q}[\chi_{\boldsymbol{p}j}] \tag{8.8}$$

for $q = 1, 2, ..., w$. When ${}_{S_q} = 0$, the S_q does not contribute anything to the solution generated by M_q,[8] whereas a large Φ_{S_q} value implies that the specified combination of M_q and S_q improves significantly problem-solving. Hence, the CDI shows that the M_q choice does not depend only on the model, but also on its optimal coordination with S_q.[9] Last but not least, if the in situ conditions make it necessary, the nonegocentric individualism underlying the epistemology of the integrative model-choice process (8.7) encourages investigators to be ready to reconsider their ideals, even when they believe that they cannot or do not want to do so.

8.3.2.2 The Nonuniqueness of Mathematical Representations

A quantitative model-choice approach that is universally applicable does not seem to exist, at this point, since model-choice ideals and goals may not have unique mathematical representations. For illustration, consider *predictability*. Some common expressions of this goal – in terms of the minimum mean square-error, potential predictability, etc. – are discussed in the literature (Neuman 2003; Boer 2004; Latif et al. 2006; Winter and Nychka 2009). An expression of predictability has been already suggested by Eq. (8.8), which offers an assessment of the predictability of $X_{\boldsymbol{p}}$ (of model M_q) from the data set S_q.

In addition to the above expressions, improved predictability may be understood in the sense that the model M_q be chosen that gives the longest predictability *ranges* across space and time, $\varepsilon_{\boldsymbol{s}}^q$ and ε_t^q, respectively. Let $c_{X;\,\boldsymbol{h},\,\tau}^{M_q,S_q}$ denote the spatiotemporal covariance function between the $X_{\boldsymbol{p}}$ values generated by the model M_q and those obtained from the data set S_q. According to the analysis of Section 5.7.3, for each model M_q one can define a $(\varepsilon_{\boldsymbol{s}}^q,\ \varepsilon_t^q)$ set such that

$$c_X^{M_q,S_q}(\varepsilon_{\boldsymbol{s}}^q,\ \varepsilon_t^q) = \eta\, c_X^0, \tag{8.9}$$

where c_X^0 is the attribute variance, and the value of η is selected by the investigator to represent the desired level of model predictability (usually, $0.5 \leqslant \eta < 1$). The

[8] To take a layperson's example, let $\chi_{\boldsymbol{p}_j}$ and S_q represent, respectively, the statements "The man will not get pregnant," and "The man was taking birth control pills," respectively. The probability of $\chi_{\boldsymbol{p}_j}$ is already very high, and the addition of S_q will not increase the probability any further.

[9] For the probabilities of Eq. (8.8) to make sense in the integrative model-choice setting of Eq. (8.7), the corresponding entities ($\chi_{\boldsymbol{p}_j}$, S_q) must be *substantively relevant*; i.e., the relevance of the entities is based on natural causation rather than mere correlations. Otherwise said, technical model efficiency takes a back seat to physical model fidelity, in which case substantive relevance is an essential component of stochastic confirmation (conditions for a dataset to provide sound evidence for, or confirm, a model assertion, prediction, etc.). Also, when using S_q to derive conditional probabilities in Eq. (8.8) the investigator should keep in mind the metalanguage issues discussed in Section 1.2.3.4 and elsewhere in the book.

$c_{X;\,\boldsymbol{h},\,\tau}^{M_q,S_q}$ provides a stochastic measure of similarity between the attribute values generated by M_q and the data values in S_q.[10] The longer $\varepsilon_{\boldsymbol{s}}^{q}$ (ε_t^q) is, the larger is the spatial (temporal) predictability of M_q. In this setting, that M_q is chosen that offers the optimal space–time range set $(\varepsilon_{\boldsymbol{s}}^{q},\ \varepsilon_t^q)$ for the situation. "Optimality" depends on whether one is more interested about spatial predictability, in which case the M_q with the largest $\varepsilon_{\boldsymbol{s}}^{q}$ value is chosen; or one is more interested about temporal predictability, in which case the M_q with the largest ε_t^q value is favored; or one is equally interested about spatial and temporal predictabilities, in which case the M_q that offers a balanced combination of $\varepsilon_{\boldsymbol{s}}^{q}$ and ε_t^q values is selected. Model predictability ranges can be also compared to those of the attribute data set S_q. If $c_{X;\,\boldsymbol{h},\,\tau}^{S_q}$ is the $X_{\boldsymbol{p}}$ covariance function calculated on the basis of S_q alone, and $(\varepsilon_{\boldsymbol{s}},\ \varepsilon_t)$ is the corresponding space–time range set, then, for a reasonable M_q choice, one would expect that $\varepsilon_{\boldsymbol{s}}^{q} > \varepsilon_{\boldsymbol{s}}$ and $\varepsilon_{\boldsymbol{s}}^{q} > \varepsilon_t$. In the limit when $\varepsilon_{\boldsymbol{s}}^{q} = \varepsilon_{\boldsymbol{s}}$ and $\varepsilon_t^q = \varepsilon_t$, the M_q may not be a good choice since its predictability power, in the sense of Eq. (8.9), does not constitute an improvement over that of the data set S_q.

Other possibilities exist regarding the quantitative formulation of model-choice. One of them is based on the *informativeness* ideal. Indeed, a variety of information criteria have been suggested in the rather rich technical model-choice literature, including the Akaike criterion, whose goal is prediction accuracy. Worth-noticing is the Bayes criterion, whose goal is average likelihood. With the information criteria approach used by model selection advocates, one penalizes models with more parameters. One can also capitalize on the relative informativeness of the physical laws linked to models M_q: choosing the best model for the situation on the basis of its relative informativeness as described in Section 7.4.2 and elsewhere in the book.

8.3.2.3 A Matter of Methodology Rather than Metaphysics

By way of a summary, so far we have seen that, depending on the problem category and the IPS ideals, one may consider different model-choice criteria. The criteria involve conditional probabilities, conditional means, uncertainty functions, dependency indicators, predictability in terms of data support or space-time ranges of the candidate models, and informativeness. These criteria may complement one another, in which case a combination of models may work best. For example, just as an ideal couple consists of a man with a future and a woman with a past, as those in the know claim, *mutatis mutandis* an ideal model-choice would combine a model with a past (in terms of its performance) and one with a future (in terms of its predictability). And, of course, if all sophisticated model-choice methods fail, there is always Marilyn Monroe's suggestion: "Ever notice that 'what the hell' is always the right decision?"

[10] It should be noticed that, instead of the convariance another depedence function could be also used, like the space–time variogram or structure function.

We conclude this section by noticing that when choosing a model, the investigator's perspective is methodological rather than metaphysical (*permitte divis cetera*[11]). One is not seeking the ultimate ideal (say, in a Platonic world) but rather to pinpoint each candidate model's precise locus of validity and truth, describe the actual conditions under which each model should work, and connect it to the observable world. Adding to the above the fact that humans are truly the "self-deceived animals," we can proceed to the next section.

8.4 Bias and Hyperreality in Model-Choice

The search for knowledge is not a carefree walk in the gardens, anymore. People increasingly realize that the infamous "bubble" is not a characteristic of the financial sector alone. Other sectors have their own "bubbles," including education (curricula that satisfy students' lower needs, overrated and outrageously expensive schools), research (strong interlocking among funding agencies, academic elites, and uncontrolled profit-seeking industries, and industry in the broad sense (pseudopractical doctrines, purely monetary goals, dumb business models, quick fixes, and flashy but substanceless tricks). A common characteristic of all these sectors is that they can drastically affect problem-solving, in general, and model-choice, in particular. The scientific quality of model-choice is linked to social, political, economic, cultural, and ideological factors. In particular, one should not underestimate the potentially serious effects of egocentrism in model-choice. As was discussed in Section 1.11.2 and other parts of the book, egocentric thought characterizes much of western lifestyle and is a central element of the corporatism outlook. It comes as no surprise that egocentric thought limits model-choice to a few personal favorites, failing to appreciate the viewpoints of others. A self-serving perspective controls the way assumptions are made, and the way data are interpreted and used. As a result, egocentric model-choice uses self-centered psychological standards (wish-fulfillment, self-validation, satisfaction of lower needs, selfishness etc.) rather than intellectual criteria (based on logic, clarity, relevance, fairness, testability, openness, self-criticism, and autonomy) to decide which models to select and which ones to reject.

The severe consequences in people's lives of their own wrong decisions and choices are emphasized in Anne Morrow Lindbergh's quote: "People 'died' all the time. ... Parts of them died when they made the wrong kinds of decisions – decisions against life. Sometimes they died bit by bit until finally they were just living corpses walking around. If you were perceptive you could see it in their eyes; the fire had gone out...you always knew when you made a decision against life...The door clicked and you were safe inside – safe and dead."

[11] I.e., to "leave all else to the gods"; *Odes*, Book I, Ode IX: 9 by Quintus Horatius Flaccus (65-8 BC).

8.4.1 Injustice as an Indicator of Lack of Civilization

Given the strong social biases, the agenda-driven elites, and the "bubble"-like corporate environment, do the best scientific models and ideas always prevail in real life? Surely not, says Scott Berkun, and he provides strong evidence that the opposite is often the case. Berkun examines several societal, cultural, and political factors that can cause a less good model to succeed at the expense of the better ones. He paints a gloomy picture in which ironically (Berkun 2007: 113–114), "The phrase ['If you build a better mousetrap, the world will beat a path to your door'] has been used as the entrepreneur's motto, misguiding millions into entertaining the notion that a sufficiently good idea will sell itself. As nice as it would be for good ideas to take responsibility for themselves. . .it's not going to happen. . .The goodness or newness of an idea is only part of the system that determines which ideas win or lose." It is often the bad ideas that "spread because, alas, they have for carriers self-serving agents who are interested in them, and interested in distorting them in the replication process" (Taleb 2008a: 220).

Many people would argue that there is little new in Berkun's and Taleb's analysis, and that *injustice* is as basic constituent of life as are water and blood. Experience has taught us that, unless the power holders have a self-serving reason to promote an individual's work, the latter will very rarely achieve any kind of recognition, regardless of its quality. There is an important issue of concern, especially for those who claim to live and prosper in what they consider advanced societies: according to many historians, the phenomenon of injustice can serve as a definite indicator of lack of civilization. In fact, the level of societal injustice as a function of geographical and temporal coordinates is inversely proportional to the corresponding level of genuine civilization at the same coordinates. This is especially true during times of Decadence.

8.4.2 Jean Baudrillard's Simulacrum

It is not uncommon nowadays to be confronted with an increasing number of cases that can be appropriately characterized as reality deprived of its substance. As Slavoj Žižek (2002: 10–11) observed, the examples vary from "coffee without caffeine" to "warfare without casualties" (on our side, of course).[12] In sciences, problem representation in terms of a model M sometimes no longer bears resemblance to the real-world system Q or anything that one might otherwise accept to be real, which is what Jean Baudrillard (1994) termed a *simulacrum* (copy or model without a real-world original). The selected model M may then assume the existence of a system Q' that has little in common with Q. Instead, Q' is a *hyperreality* that is no longer based on anything identifiably real: unrealizable imagination

[12] This was General Colin Powell's doctrine, as the readers may recall.

triumphs over substance. Many health studies are rather profound examples of simulacra (Section 9.4). For many physicists, string theory is a form of hyperreality: it has no real counterparts, and it is neither experimentally testable nor falsifiable (Smolin 2006). Although imagination is one of brain's abilities to generate an extraordinary mental life, it is imagination turned into delusion that can create the most nonsensical kinds of hyperreality. This is true for almost any domain of human inquiry.

8.4.2.1 Simulacra in Finance and Politics

Arguably, the Wall Street stock market has never been much more than a simulacrum of trade, built on hot air, hype, and greed. The simulacrum included the excessive faith in dumb models that had little to do with reality, thus contributing greatly to the collapse of the financial markets, with tremendous consequences worldwide (Taleb 2008a, b; Salmon 2009). We have already criticized this corporatism-driven simulacrum that characterizes the decadent period underway, and there is no reason to further address it here. Because no man wants to be left behind when it comes to creating one's own hyperreality, in a famous remark to Ron Suskind, an aide to President George W. Bush told the veteran journalist that people like Suskind were "in what we call the *reality*-based community" (Suskind 2004). According to the aide, these are people who stubbornly "believe that solutions emerge from your judicious study of discernible reality." But the administration doesn't share their empiricism, which, like the Treaty of Westphalia of 1648 that helped usher in a long era of international diplomacy among nation-states, is rooted in the Enlightenment. All that rationality, that helped us climb out of the Dark Ages, is now mere history. "That's not the way the world really works anymore," the Bush aide elaborated. "We are an empire now, and when we act, we create *our own* reality. And while you're studying that reality – judiciously, as you will – we will act again, creating other new realities, which you can study too, and that's how things will sort out." Perhaps, the best response to this nonsense is Einstein's quote: "Two things are infinite, the Universe and human stupidity; and I am not sure about the Universe." Next, we consider some more characteristic cases of hyperreality, which, in order to cover up for intellectual inadequacy about the subject matter, resort to the kind of arguments that Wittgenstein characterized as "insidiously disruptive forms of nonsense."

8.4.2.2 Congregatio de Propaganda Fide[13]

Immanuel Kant summed up the matter in a laconic yet highly poignant manner: "Reason suffers the fate of being troubled by questions which it cannot reject

[13] Congregation for the Propagation of the Faith.

because they were brought up by reason itself, but which it cannot answer either because they are utterly beyond its capacities." Taking advantage of the situation, and having nothing really constructive to offer, radical feminists look down on reason and have no respect for science but, instead, they chose to live in a state of extreme hyperreality.[14] As a result, the radical postmodern studies they produce incorporate everything that can defy reason and sock feeling. Let us look into the evidence more carefully.

In his work *In praise of Intolerance to Charlatanism in Academia*, Mario Bunge mentioned the case of the feminist theorist Sandra Harding who went as far as to call Newton's laws of motion "Newton's rape manual," the rape victim being Mother Nature (Bunge 1996: 101). Famous is the line by Judith Butler and other radical feminists in the 1970s–90s that gender has no biological basis but is entirely socially constructed (Eller 1995, 2002). Along the same line of bizarre reasoning is Katherine Hayles' article "Gender encoding in fluid mechanics: Masculine channels and feminine flows" (Hayles 1992). Extreme feminist claims also include Luce Irigaray's suggestion that "fluid mechanics is underdeveloped with respect to solid mechanics because solidity is identified with men and fluidity with women" (Sokal 2008: 124). Astonishingly, such gross misrepresentations of reality—many of which could belong to the domain of Monty Python's kind of dark comedy—have a significant influence on certain fields of academic research and education. For example, feminist studies in social geography (Bondi 1999; Kwan 2002; Nightingale 2003; Gilbert and Masucci 2005) constitute a classical case of miming the work of significant sociologists and philosophers but completely missing their deeds. The postmodern studies involve a jargon and pseudotechnical lingo that provide a false profundity, but do not allow an open communication with scientific disciplines that could easily demonstrate the chimerical nature of what these social geographers believe to be the most solid parts of their professional lives. Mei-Po Kwan, e.g., proudly declares that her approach "is inspired by feminist critiques of modern science and visualization technologies and by poststructuralist feminist notions" (Kwan 2007: 22), that her "GIS art project intends to challenge the understanding of GT [geospatial technologies] as scientific apparatus for producing objective knowledge" (ibid: 28), in which case she suggests "making emotions, feelings, values, and ethics an integral aspect of geospatial practices" and that these "practices should also take into account the existence of different kinds of bodies (e.g., pregnant, disabled, old, mutilated, dead)" (ibid: 24–25). Kwan's model consists of some of the densest, most impenetrable verbiage in existence. Yet, it is impossible to present it in a way that does not introduce premises that are obviously wrong. Kwan's objection to scientific (objective)

[14] The works of these feminist theorists, who are active mainly in academic environments, must be sharply distinguished from endeavors with very different objectives, such as the scientific study of feminine conditions (social, biological, etc.) and the women's emancipation from male domination. Instead, radical feminists place ideological belief in the progress of women above truth, justice, equality, fairness, and scientific methodology, and they often claim to speak on behalf of all women.

knowledge on the basis that people function on a purely subjective, emotional, and personalized approach does not carry much water. People also often get their sums wrong, but this is not a good enough reason for advocating a change in the objective foundations of arithmetic. In reality, Kwan's inspiration—hypnotic and mesmerizing as it may be—has nothing to do either with science or with rationality. Nevertheless, feminist geographers seem to justify their views by their privileged access to a higher vision. They feel free to treat the facts in a contingent manner, because they are so utterly confident in the virtuousness of their motives. As many scholars have observed, there is nothing even remotely rational about the reasoning process underlying the feminist geography model, which would be best characterized by Wolfgang Pauli's famous quote: "It's not even wrong". No doubt, radical feminist theorists have always felt liberated from any boring reliance on scientific facts. In which case, they should not hesitate to take up Alan Sokal's challenge: "Anyone who believes that the laws of physics are mere social conventions is invited to try transgressing those conventions from the windows of my apartment (I live on the 21st floor)". Uncomplicated, isn't it?

Although it is left to radical feminists of all sorts to figure out whether Sokal is being facetiously metaphorical or not, there are serious matters of sound reasoning and creative synthesis of opposing perspectives that do not seem to concern those gathered in the Conclavium of radical feminism. Instead, their main goal is to establish a *congregatio de propaganda fide* that aggressively promotes their model of life and excommunicates all other viewpoints (in the process, all kinds of tricks that the Conclavium has mastered over the years are used, such as silencing their critics on the basis of "political correctness," and outrightly manipulating the scope of human inquiry). As is usually the case with such agenda-driven models of life, they eventually begin to look as futile as they really are and collapse under the weight of the unbearable nonsense they produce—often at a considerable cost to the disciplines that accommodate them. Which is probably why the philosopher Jürgen Habermas characterized radical postmodernism's apparent embrace of irrationality as morally corrupt.

8.4.3 Manus Manum Lavat[15]

In many cases of institutionalized research and corporate science, the focus is on the banal exchange of technical opinions. Creative thinking and bold hypotheses are often replaced by an almost uncontrollable urge to obtain the latest and reassuringly expensive experimental equipment, and use the most computationally demanding scheme. In a very real sense, many researchers *are* what equipment they *use*, in a similar way that many people *are* what they *eat* (as the rise in obesity in U.S.A. signifies).

[15] I.e., "one hand washes the other" or "the favor for the favor." Attributed to Petronius.

8.4.3.1 The Post-Science Era and Carmen Electra

Following inappropriate practices in science administration is not uncommon. Infamous is the case of the sweeping investigation of a former NIEHS director by the U.S. Congress "for a variety of management and ethics issues" (Hileman 2007). Another example is a report issued by the U.S. National Research Council that is highly critical of E.P.A.'s peer-review process. The report notices that current policy allows the same individual who manages a scientific research project to serve as the peer-review leader for that project (White 2000). Indeed, the best way to make sure that the scientific model you propose is chosen for funding is to be you who decides which model the funding agency will chose.

It has become clear by now that one of the consequences of the serious lack of political leadership in the E.U. (European Union) is the abysmal degeneracy of its research funding system. The beginning of the twenty-first century has found the E.U. in a *post-science* era, in which the practice of normal science has been taken off center stage. Normal science's value system based on truth, honesty, openness, and equal opportunity is mostly a thing of the past. The post-science E.U. elites have hidden agendas and private ways of communication that largely exclude the vast majority of scientists. In most cases, the emphasis is on appearances and celebrity culture rather than substance and meritocracy. In Brussels, highly paid E.U. bureaucrats (also known as *Eurocrats*; Warner 2007) are basically interested to cultivate relationships with sophisticated chefs, fashion designers, and luxury car dealers. Describing the life of the privileged species of Eurocrats, Max Haller (2008: 178) writes: "Members of the Eurocracy who do not work enough are unlikely to be confronted with disciplinary action because the staff is very litigious and soon goes before a court where he usually wins against the commission. . .they live in a Cockaigne (*Schlaraffenland*), given their opulent salaries, allowances, pension schemes, and tax system." At the same time, it is common knowledge that E.U. administrators are uninspiring politicians[16] who have little interest and/or knowledge of research matters. It is characteristic that the public speeches of these E.U. politicians leave citizens the impression of an army of pompous phrases and statements moving over the landscape in search of an idea. Yet most of them have engraved deep in their hearts and minds the Carmen Elektra motto: "Life is not worth living, unless there is a camera around." In a sense, one is dealing with a post-science system that has brought back the ancient distinction between a very small governing elite and the largely disenfranchised and voiceless population that does not participate in any decision or policy-making process, including the identification of worthy research problems, fair model-choice processes, and sound solution objectives.

[16] Brought to power by uninspired voters, some argue.

8.4.3.2 Weak States of Scientific Development

There exist a growing number of alarming reports worldwide concerning the increasingly negative role of academic bias in scientific inquiry. Such a bias, when unchecked, may lead to the study of poorly conceived problems, the development of inadequate techniques, and the derivation of nonsensical solutions. Strong biases can be found in disciplines that are at a *weak state* of development. This includes some modern disciplines and those emerging from the blending of others. Their theoretical background is not strong, there is no sufficient number of informative observations available, and opposing views exist concerning the scope, reasoning mode, and methodology of the new discipline. According to Feynman (1998: 22), "Many sciences have not been developed this far, and the situation is the way it was in the early days of physics, when there was a lot of arguing." Naturally, if a discipline is at a weak state of development, there is more uncertainty in model-choice, more questions of knowledge reliability and, sadly, more opportunity for dubious elites of all kinds to influence the outcomes of different investigations and even make suggestions that belong to the sphere of hyperreality (Klee 1997). For example, many readers may have experienced the strange phenomenon where disciplines vulnerable to postmodern ideas have convinced themselves that by changing a word in their name, automatically makes them more scientific.

Typical examples of disciplines at a weak state of development are certain public health related fields (clinical research, epidemiology, human exposure, etc.), during periods when basic science, for whatever reason, has no solid answers to offer. The matter has been studied to a considerable extend. In medicine, critics argue that EBM (evidence-based medicine) should be better characterized as epidemiology-based medicine, where statistical analysis (randomized controlled trials etc.) are at the top of the so-called hierarchy of evidence, "placing other factors relevant to clinical decision-making (intuition, theories, personal experience, and, significantly, professional judgment) lower down the scale… Practitioners who fail to 'comply' with EBM methods are castigated for their ignorance and 'conservatism' " (Loughlin, 2010: 69–70). Given that medicine is an empirical science, EBM's emphasis on evidence makes one wonder whether its proponents believe that there can be any other kind of medicine. "Part of the difficulty of the current epidemiologic paradigm is that it persists in talking about modern interdisciplinary problems in an outmoded vocabulary" (Christakos 2005: 2). This viewpoint was echoed, *inter alia*, in Wasim Maziak's statement that, "While epidemiology is likely to be increasingly called upon to make sense of the risks involved with these changes, wading into this era with a mindset and tools that were derived from epidemiology's 'golden era' of tackling major risk factors, has created more confusion than understanding" (Maziak 2009: 293).

The peer review system used to be the backbone of scientific inquiry. It involved the evaluation by experts of the creative work, innovative ideas, and high quality new results obtained by scientists in the same discipline in order to maintain or enhance the quality of the work or performance in that discipline. Peer reviewing aimed at excellence in academic and scientific research; it was based on an honor system that embodied values of responsibility, integrity, and trust; and it strongly discouraged any sort of bias, fraud, and cronyism. *Alas*, mounting evidence shows that this is the case no more. It is astonishing that the majority of the most highly cited clinical research findings of the past fifteen years have subsequently been refuted, whereas epidemiology results had been contradicted in four fifths of the cases examined (Ioannidis 2005). No doubt why, as noted earlier, the U.S. Supreme Court openly questioned the authority of the peer review process. Furthermore, by means of a detailed evaluation of the reviews of papers submitted in scientific journals, Peter Rothwell and Christopher Martyn obtained quantitative evidence that the process (journals, research review panels, etc.) by which the established system allots research funding and scientific prestige is a nonvalidated charade that often generates results little better than chance (Rothwell and Martyn 2000; Horrobin 2001). This kind of a review process favors the elite and its loyal servants, and blocks innovation and creativity, which makes it a prime reason that public support for science continues to erode. James Delingpole (2009) refers to evidence suggesting that prominent climate scientists have been involved in[17] "Conspiracy, collusion in exaggerating warming data, possibly illegal destruction of embarrassing information, organized resistance to disclosure, manipulation of data, private admissions of flaws in their public claims and much more." It is disappointing and concerning, indeed, that in this rat race for recognition and financial gain actual science takes a back seat.

Remarkably, researchers in the field of cognitive science have found significant evidence that there are serious limits on the ability of investigators to criticize their own models showing, instead, clear signs of bias and self-deception when it comes to considering their perspectives, presuppositions, and other mental creations (Goleman 1996). According to Thomas Martin (2007:76), e.g., even very competent investigators and people with high levels of scientific literacy routinely subordinate scientific evidence to their own deeply ingrained cultural suppositions. He notices that, "some very striking examples in the realm of professional science itself," where "leading disciplinary practitioners who feel threatened by unorthodox new findings will sometimes band together to suppress such information, with the explicit intention of blocking its appearance in the journals." In this respect, the ruling elite is using taxpayers money to prevent other scientists from advancing science, which in the end is against the public's own interest. Not surprising, this is basically the same approach used by financial corporations: After the 2008 financial crisis, e.g., the U.S. banking system used the taxpayers bailout money to lobby against the proposed credit card and other reforms designed to benefit the taxpayers (i.e., the taxpayers funded their own financial destruction). This shows, once again, how much in common corporate science has with financial markets. Long time ago, Petronius had an appropriate characterization for these self-serving elites: *Manus manum lavat!*

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[17] http://blogs.telegraph.co.uk/news/jamesdelingpole/100017393/

8.4.3.3 Charlie Chaplin's Incident

Whichever way one looks at the matter, the above situation represents a remarkable case of bias in science with a dose of hypocrisy on behalf of otherwise accomplished scientists. Martin remarked that, "While these luminaries undoubtedly convince themselves they are merely upholding the integrity of their fields, the truth is that they (in quintessentially human fashion) are often more interested in preserving cherished beliefs than in encouraging potentially disruptive discoveries." In the end, the system reaches an advanced state of *self-denial* in which nothing outside its own agenda matters anymore, and the capacity for recognizing quality work, highly original findings, and gifted individuals is permanently lost. At this point the readers may appreciate a little dose of humor. In 1930, Charlie Chaplin decided to participate to a talent contest in which the participants had to mimic famous people. Chaplin mimicked himself and he came ninth. This amusing yet telling incident shows that system's state of self-denial often leads to the system's *self-ridicule*.

Chaplin's is one among many incidents in which system's incompetency and self-serving agenda led to its complete loss of credibility. Among the most recent and widely known cases are those of respected academics and financial analysts whose models gave top grades to investment banks and other financial institutes just a few days before their 2008 collapse. In such an environment, it is not unusual that many young scientists have to spend their entire professional lives fighting hard under very difficult circumstances to establish the legitimacy of their often brilliant research work. They may even have to carry out a *social revolution* at the same time.

8.4.4 Sir Laurence Olivier's "Stardom," and Bette Davis' "Big way"

The above deeply disturbing state of affairs has been linked with the current "stardom" element of science, which puts more emphasis on appearances, made up celebrities, and networking rather than substance and meritocracy. In its effort to promote its agenda and secure more state and government resources for itself, the established system (including academic and institute administrators, disciplinary-based societies, and organized groups) methodically creates "stars" among its members.

8.4.4.1 A "Bigger-than-Life" Showbiz Cult

The clerkdom-controlled system supports the work of its "stars" in a big way. Undoubtedly, in this respect the system has learned a lot from the promotion techniques and corporate tricks of Show Business. Movie lovers may recall, e.g., a scene from the hit movie *Deception* (1946), in which Bette Davis points out to a talented foreign musician: "Music is different in America. . .like everything else it must be done in a big way. . .if you start in some school or suburban concert hall, it's much too difficult and it takes too long." In other words, in order to succeed one needs to belong to the so-called "bigger-than-life" showbiz cult. Similarly, the "scientists-stars" must be somehow parachuted into the center of the stage without having the trouble to climb on it. As they say, the best way to enter a profession is to be *born* into it. This is literally the case of faculty promoting their offspring—an amusing situation that has a long tradition in human affairs: *Gloria filiorum patre*.[18] Another example is worth-mentioning. In an effort to advocate for their discipline's narrow self-interests, some academics often resort to showbiz tactics. It is comico-tragical to watch the level of profound exaggeration turn into self-ridicule that they reach in their effort to glorify their discipline's "stars," as a way to elevate discipline's prestige (especially when the discipline lacks recognition, is considered scientifically "thin," or is in a state of decadence). As is expected, instead of impressing their colleagues in other disciplines, the showbiz academics only manage to lose credibility, and in the end they do a bad service to their own discipline.

To paraphrase a famous quote by Sir Laurence Olivier,[19] the scientific stardom situation has created a strange state of bluffing: Once we had good scientists, some of whom would become well deserving stars in their field of expertise; now we have system-made "stars," very few of whom become good scientists. This quote represents one of the clearest representations of the phase of civilization we are in. A phase in which the most commonplace achievement of the "star" is presented as a path-breaking event in the field, a fact that sometimes brings ridiculous connotations to one's mind. It has been said, and I believe with good reason, that in today's media one can find side-by-side slogans like, "This is a book that has revolutionized its field," and "The Panzini-brand spaghetti has revolutionized cooking." "Publication of the book [Wernick and Aarsvold 2004] was underwritten by the U.S. Department of Energy, which provided funds to distribute free copies of the book."[20] The system's involvement knows no bounds when it comes to aggressively promoting its agenda, at the same time showing little or no concern about ethical issues (unequal opportunity, favoritism, unfair competition, and the like). One wonders how many distinguished authors have enjoyed the same treatment by the government. Sadly, in the time of Decadence all that matters is to be among those who Paulo Coelho (2008) calls "The ultimate winners of the hedonistic game of modern life."

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[18] The glory of sons is their fathers. Typical is the case of the "star" professor whose career is built by his papa professor's network (papa knows best). The "star" conveniently obtains his doctorate in papa's institute and co-authors several of papa's publications. Papa's network takes care of everything, and the "star" does not need to produce any original research worth the large amounts of funding he receives.

[19] "We used to have actresses trying to become stars; now we have stars trying to become actresses."

[20] http://www.iit.edu/mirc/research/textbook.shtml

8.4.4.2 Faster than the New Orleans Levees

To gain scientific credibility, one's models must find their way to the pages of the best journals of the field. This is a critical step of a model-choice process, one that can make any effort toward the development of a rigorous model-choice approach (Sections 8.1 through 8.3) totally irrelevant, regardless of its potentially high quality and originality. This is why when it comes to considering papers from "star" scientists, the strict acceptance standards of otherwise prestigious journals give away faster than the New Orleans levees. The end result of this policy is a considerable loss of the journals' credibility. To illustrate the point *bona fide*, it suffices to provide a few examples from well-known journals.

Infamous is the 1998 paper about the MMR (measles, mumps, and rubella) vaccine published in the medical journal *The Lancet*. The paper, whose lead author was Andrew Wakefield, claimed that a definite connection existed between the vaccine and autism, which caused vaccination rates to plummet in UK, resulting in a large increase of measles and mumps cases. It was soon discovered that Wakefield had manipulated data, misreported results, and avoided mentioning test results known to him to contradict his theory. It was also discovered that Wakefield had received major funding from British trial lawyers seeking evidence against vaccine manufacturers (Beer, 2004, 2006). In 2004, the interpretation section of the paper was retracted by ten of the paper's 13 coauthors. Still, it took several more years until the journal fully retracted the paper in 2010 (The Editors of *The Lancet* 2010), but this was little compensation for the deaths and injuries caused by the sharp drop in vaccination rates (Burns, 2010). In the case of the microelectronics expert Jan Hendrik Schoen, the fraud was so extensive that in 2002 the journal *Science* withdrew eight papers written by the "star" researcher and in 2003 the journal *Nature* similarly withdrew seven papers by Schoen (see, Agin 2007). Similar is the case of the biomedical research "stars" Kim Tae-Kook and Hwang Woo-Suk, who had made it their habit to fabricate their experimental results, and *Science* had made its habit to publish them uncritically (Reiser 2008). *Science*, *Nature*, and *The Lancet* are not, of course, the only scientific journals that, in their ruthless hunt of publicity, have managed to embarrass themselves and whatever they represent. These are just the high-profile cases. Matters are worst with many other journals controlled by the elites of the corresponding disciplines. Faithful to the corporatism spirit, these elites use the journals for self-promotion and to control large amounts of research funding, regardless of the cost to basic human values.

This being the current state of affairs, there is an infinitesimally small amount of hope that some of the above elite scientists will be moved by reading the following passage from Bertrand Russell's commentary about Gottlob Friege:

> As I think about acts of integrity and grace, I realise there is nothing in my knowledge to compare with Frege's dedication to truth. His entire life's work was on the verge of completion, much of his work had been ignored to the benefit of men infinitely less capable, his second volume was about to be published, and upon finding that his fundamental assumption was in error, he responded with intellectual pleasure clearly submerging any feelings of personal disappointment. It was almost superhuman and a

> telling indication of that of which men are capable if their dedication is to creative work and knowledge instead of cruder efforts to dominate and be known (Klement 2001: 23–24).

8.4.4.3 Oscar Wilde's "De Profundis"

It is infinitely sad that discordant or dissident voices are stifled by the wider utilitarianization of a society that has no more room for a robust value system, since it is increasingly filled by advertising slogans of substanceless things. A society incapable of appreciating a moving passage from Oscar Wilde's *De Profundis* (Wilde 1905: 147):

> We call ours a utilitarian age, and we do not know the uses of any single thing. We have forgotten that water can cleanse, and fire purify, and that the Earth is mother to us all. As a consequence our art is of the Moon and plays with shadows, while Greek art is of the Sun and deals directly with things.

For the outsiders, the nonelite members, *non est ad astra mollis e terris via*.[21] Otherwise said, the outsiders know full well that they cannot compete against the "stars" and elites on a playing field that was created for elites' benefit alone. This is a time for reflection and cross checking; a time for dietary discipline in images and sounds generated by the decadent stardom that seeks to control people's lives. Too much light can blind rather than enlighten an individual. One must be constantly aware of the valuable things that are at risk. After all, just as the five-star hotels of industrial tourism, the established system can offer luxury but not class.

[21] "There is no easy way from the Earth to the stars" (Seneca the Younger).

Chapter 9
Implementation and Technology

For a successful technology, reality must take precedence over public relations, for Nature cannot be fooled.

R. Feynman

9.1 "Thinking About" Versus Merely "Searching for" a Problem-Solution

It is possible that some readers find the book full of notions of abstract reasoning that would astonish a medieval theologian, so to speak. Nevertheless, it becomes clearer by the day that in the emerging Conceptual Age to be able to reflect on abstract ideas and relationships, understand notions that are removed from the mere facts of "here and now," and perceive analogies between what appear to be totally unrelated entities (and thereby understand higher levels of abstraction), will be the key to the solution of the increasingly complex and subtle problems that characterize the 21st century. As noted several times in this book, the theory of simple ideas and "quick and dirty" solutions is under increasingly suspicion nowadays, and the far-reaching consequences of this suspicion are yet to be assessed. In this respect, it is unfortunate that most investigators with strong abstract reasoning skills prefer to focus highly specialized mathematics rather than apply their skills to concrete in situ problems that require to establish sound theory-interpretation associations, make abstract ideas concrete by showing their relevance to action, and acquire a basic understanding of the reasoning modes of the other investigators participating in integrative problem-solution. In sum, achieving some kind of balance between the abstract and the concrete is in order. The success of any Epibraimatics theory depends, to a considerable extent, on the construction and skillful operation of an adequate IPS *apparatus*. This apparatus includes a set of theoretical concepts and tools for tackling a specific kind of problems, and codes for performing the calculations on a computer. The role of the latter has become so important that, for many scholars, has led to its evolution from computer-as-tool to computer-as-nature. Crucial elements of the successful operation of an IPS apparatus are the creative imagination of the theorists who develop its abstract

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framework, the skills of the programmers who construct the codes, *and* the adequate *communication* between the two. Among other things, on the basis of this communication the investigators can cultivate the precious ability to guess what will happen in a given in situ situation before using the sophisticated technical means of the apparatus, thus vastly improving the quality and reducing the cost of the IPS process. Last but not least, an investigator should not forget that, as we saw in Sections 1.3–1.5, the established forms of collective life (social structure, political agenda, educational system, research policy, and administration) can have a direct and immediate effect on the forms of thought that the individual investigator is able to consider, including what problems to study, and what theories, methods, techniques, and experiments to use.

9.1.1 The Role of Software Codes: Duco Ergo Sum?[1]

In situ implementation of the IPS appartatus usually requires the development of computational models involving software packages of varying levels of technical sophistication. This *link* between theorization (concepts-models) and action technology (hardware-software) is absolutely critical, yet its importance is often underestimated. The link relies on a regular gradation of the investigators' intellect to harbor and diffuse ideas rather than a "brute-force" approach. The potential dangers of this approach should not be underestimated. In many cases the two sides of the link have little in common or even contradict one another: the reasoning underlying the technology is not consistent with that of the theory it is supposed to put into practice; the two sides may not even refer to the same phenomenon; the meaning of a concept in theory may be very different from its counterpart in the software or the experiment. In PCU campuses, an increasing number of students use the computer to develop the skill of *searching* for a problem-solution so that they no longer need to cultivate the skill of *thinking* about the solution. Researchers and educators call our attention to this situation, and the need to face it in a timely manner. Among them, Ladd (2006: 444) concluded, "The most important thing we should be teaching to introductory students is not how to use routine statistical procedures by pushing buttons on a computer, but how to make risky assessments and judgements." The technology available nowadays, including that which involves powerful computers and *visualization* tools, is not merely *duco ergo sum*, but has an intriguing cognitive dimension as well. Among other things, technology could enable us to "see" things that are invisible or inaccessible to the unaided eye, and make it possible to obtain certain forms of solution to in situ problems that cannot be derived by conventional analytical methods.

To illustrate the value of integrating physical modeling tools with powerful visualization technology, Kolovos et al. (2010) suggested the blending of space–time

[1] I calculate, therefore I am?

analysis (BME) with a cognitively informed visualization of high-dimensional data (Spatialization). The combined BME-Spatialization approach (BME-S) was used to study monthly averaged NO_2 and mean annual SO_4 measurements in the state of California over a 15-year period (1988–2002). Based on the original scattered measurements of these two pollutants, the space-time analysis (Section 7.5) generated spatiotemporal predictions on a regular grid across the state. Subsequently, the prediction network had to undergo a spatialization transformation into a lower-dimensional geometric representation aimed at holistically revealing patterns and relationships that exist within the input data. In this way, the BME-S approach generated an array of visual outputs that offered insight and perspective, and facilitated the understanding of the underlying mechanisms that govern the spatiotemporal distribution of the NO_2 and SO_4 pollutants (see visualization in Fig. 9.1). A definite advantage of the BME-S generation of cell-level predictions is that NO_2 and SO_4 can be integrated despite differences in the spatial distribution of the monitoring stations. If NO_2 and SO_4 concentrations were evolving in lockstep, subject to the same forces in the context of a particular cell, then one would expect to see no organized patterns in the distribution of NO_2 and SO_4 across spatialization. A strong organization is observed instead, with the largest part of the pollutant distributions being separated into contiguous regions in the SOM (self-organizing maps). It is apparent that the dominant NO_2 pattern is the rapid decline of predicted annual concentrations, after peaking around 1990, with a slight increase after a 1997 minimum. Meanwhile, SO_4 showed a similar pattern up to its 1997 minimum. After that, many cells seem to have experienced a rapid rise in SO_4 concentrations. Exceptions from these broad

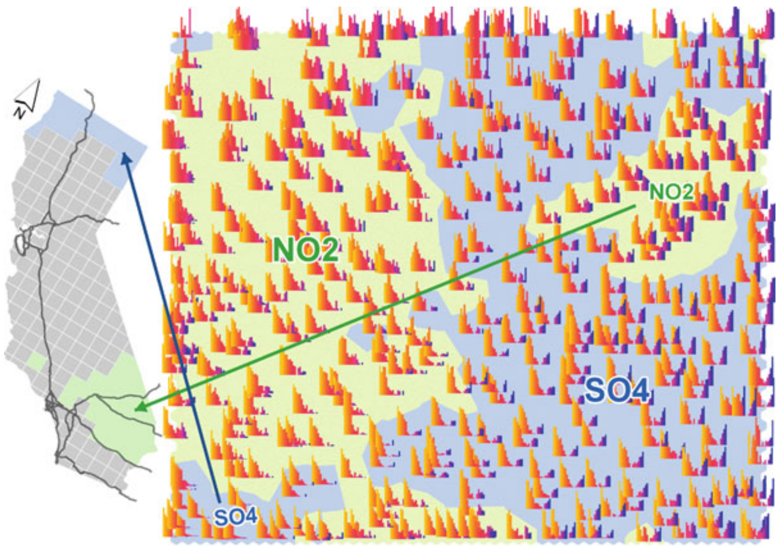

Fig. 9.1 Visualization of monthly NO_2 values (California, 1988–2002) represented as 180-dimensional vectors. Bar charts show annual sequence of January NO_2 values according to neuron vectors (From Kolovos et al. 2010)

patterns include the continued decline of SO_4 concentrations in the extreme north of the state and the rapid rise of predicted NO_2 concentrations in the Mojave Desert, north of highway I-10. The SOM can also register graduated temporal regimes, (e.g., when one crosses the imaginary boundary between the NO_2 and SO_4 regions at the center of the SOM).

The potential value of technology (software, visualization, etc.) should be constantly assessed within the appropriate conceptual framework of meaning and value (Sections 3.5–3.10). This assessment would face questions such as "Should a technology be evaluated in terms of the really meaningful operations it can perform automatically?" The key to the answer to this kind of questions may be found in Alfred North Whitehead's ambiguous quote: "Civilization advances by extending the number of important operations that we can perform without thinking of them."

9.1.2 The User–Software Relationship

There are several software libraries for specified IPS purposes. The doubting Thomases should try the various libraries and draw their own conclusions. In any case, the important matter is that the relationship of the user with the software should be one of substance (understanding the underlying concepts and methodology, adequately fusing form and content in an indivisible whole) and not a "brute-force" approach. This relationship should consider software libraries not only as a medium of experience and theory implementation, but also as a resource for generating theory and method in the study of the in situ problem.

Generally, the KBs processed by the software libraries include data obtained by the investigator's senses and by means of sophisticated equipment (Sections 1.7 and 3.6). Seeing is so important that the investigator's vision system will not cease to seek data even when their quality is very poor and their quantity very scarce. While some of the KBs include rigorous quantitative assessments, many others are about multi-sourced belief systems. An investigator does not study directly the beliefs, but rather the sentences that people use to state them (Section 3.7). There is a certain amount of hazard in this, which is yet another good reason for using stochastic reasoning concepts and methods to represent the KBs (Sections 5–6). Albert Camus wrote: "It is natural to give a clear view of the world after accepting the idea that it must be clear." The tools of scientific inquiry (theories, techniques, experiments) are human constructs with practical objectives that are as clear and meaningful as the world perspective they are built upon. Software libraries offer powerful demonstrations that a world perspective can have significant practical consequences. For example, the SEKS-GUI software library (Kolovos et al. 2006; Yu et al. 2007a) is built upon the premises that problem-solutions should be generated in the most economical way that is, at the same time, maximally informative and adaptative, allows for user–library interaction, accounts for KBs that are relevant to the problem, and includes procedures for solution verification. Visualization tools are used that offer useful means for turning one's data into insight and foresight, and the users of the software library are encouraged to be active participants of the process rather than bench-warmers who do not take part in the dance.

The indisputable role of foresight in human inquiry was emphasized in Sir Arthur C. Clarke's observation: "It is vital to remember that raw data is not knowledge, that knowledge is not wisdom, and that wisdom is not foresight." Foresight is usually expressed quantitatively by the more technical terms "prediction" and "mapping" (Section 7.6). In the same technical setting, probability models express the investigator's ineradicable uncertainty about the in situ situation, and the generated predictions are only as good as the assumptions behind them. The development of software libraries should incorporate specified procedures for testing the libraries themselves. The proper *interpretation* of a software library include the way it works, i.e., how it manifests, clarifies, sharpens, and extends the input theories and models. The above features, combined with the unique characteristics of knowledge synthesis, can render the software libraries valuable additions to the spectrum of analysis, modeling, and interpretation tools of IPS.

9.2 The Need for Creative Participation

Using a software library is a creative process in which the users create and generate meaning out of their own experience with problem-solving. Indeed, the library's interactive means establish a dialectic between the library user and the natural system of interest. Any results generated by the library are the cocreation of the user and the software. Each phase of the library may have a certain subjective flavor that depends on the user's experience, presumptions, theoretical background, and even psychological state at the time of the analysis. The user may appeal, e.g., to discipline-specific assumptions and extra-data sources in order to resolve conflicts and inconsistencies within the theoretical IPS framework.

9.2.1 Ezra Pound and the Prince of Darkness

In his memoir *The Prince of Darkness*, the influential political reporter and Washington insider Robert D. Novak describes his encounter with the famous poet Ezra Pound, in the early stage of his career. Novak admitted to the poet that he planned to spend his entire life in journalism. "Well then, in that case, I have a piece of advice for you," Pound said, "above all, avoid too much accuracy." According to Novak's interpretation, the poet's advice was that one should make sure not to let a plethora of little facts get in the way of the greater truth (Novak 2007: 40–41). Ezra Pound's suggestion makes sense in the context of the media-dominated modern society. Many volumes have been written concerning this matter and its huge societal and political implications, but they are not the focus of the present book. Rather our concern is whether Ezra Pound's advice is worth considering in scientific investigations too. As in other cases considered in the book, the answer to this question depends on the context of the phenomenon considered and the content of the investigator's thinking style. Accordingly, Pound's suggestion makes sense in many real-world problems that cannot be solved exactly, in which case it is common practice to suppress superfluous details and focus only on the most relevant information, neglecting the effect of factors that are unimportant for the particular problem. It is then necessary to estimate the magnitude of the quantities to be neglected and the resulting accuracy loss. Pound's advice should be also kept in mind when a software library user makes critical decisions, such as the amount of data to be processed and the meaningful approximations to be made at the various library stages. For example, in spatiotemporal analysis it may be meaningless to include in the prediction calculations any number of data (however large) that lie beyond the space–time dependence ranges. Also, analytical and computational manipulations can be reduced significantly if the investigator has a deep understanding of the phenomenon that permits him to transform the relevant equations in a more manageable form (by eliminating physically unimportant terms, using meaningful approximations, etc.).

9.2.2 Data Versus Interpretational Uncertainty, and Descartes' Skull

Nobody can escape uncertainty and its potentially severe consequences, not even Rene Descartes, one of the fathers of determinism. His body has been picked apart ever since he died in Sweden in 1650. Among other remarkable incidents before Descartes' body was returned to France, include the French Ambassador helping himself to the philosopher's finger, and a Swedish guard taking the head for financial gain. Since then, the true whereabouts of Descartes' skull remain highly uncertain (Shorto 2008).

Uncertainty characterizes almost every stage of a problem-solution, from abstract analysis to software implementation. The software user often is not the person who obtained the data that are processed by the library. However, the user needs to rigorously account for *data uncertainty* when developing the relevant functions of the software library. The emergence of uncertainty in every step of the IPS process requires the investigator's active participation. As we saw in previous chapters, data uncertainty arises in a twofold manner: the act of measurement may disturb the natural system, often in an unpredictable way (objective manner); and the agent's theoretical background influences which sorts of attribute properties should be measured and, hence, plays a decisive role in the construction of the measurement apparatus (epistemic manner).

In addition to data uncertainty, there is uncertainty linked to the proper interpretation of the theory that describes the measured entities and the representation of the underlying reality. Indeed, reality is often not perceivable directly by the investigator. Instead, the investigator builds a theoretical model of reality and relies on its measurable or observable effects (described by the model) in order to obtain an appraisal of specified aspects of reality. Then *interpretational uncertainty* is the result of important differences that arise within the trinity "reality-theoretical model-measured entities" and need to be accounted for by an appropriate theory interpretation. Correspondingly, these differences include reality as actually *is* versus the way it is projected to be by means of its measurable aspects as described by theory; and an "ideal" measurement device conceived by the theory versus the "actual" device used to make measurements in practice. For example, investigators do not individually observe via their senses each one of the trillions of elementary particles and the forces that move them at the most fundamental microscopic level of the world. Instead, investigators are "crude" measurers of the net effects of these microscopic entities at the macroscopic level of what is called the classical world. These effects are described by a theoretical model: elementary entities (atoms) have been "seen" only indirectly by means of their measurable effects (as described by quantum theory), and they presumably exist even if no human agent has seen them directly. Accordingly, a crucial distinction is made between reality (atoms unseen) and their measured consequences (collective motion of atoms investigators witness with their senses), the distinction being a matter of an adequate quantum theory interpretation.

9.2.3 The Man and the Hammer

A familiar scene in today's world is that of expert practitioners claiming to have 20–30 years' experience, when in reality they have had the *same* experience over and over for 20–30 years in a row. Where are the roots of this self-deception? An answer to this question may be offered by the intriguing metaphor shown in Fig. 9.2. The continuing implementation of a tool makes it indistinguishable from the worker who uses it. At the beginning, the hammer can be seen as a tool that accomplishes a specified task. But the more the worker uses the hammer and gets comfortable with it, the less he distinguishes the hammer from himself. Moreover, the worker cannot distinguish the hammer itself from how it fits into the task at hand.

Fig. 9.2 When the tool becomes the agent (Action Philosophers: "Jean-Paul Sartre" copyright © 2006 Ryan Dunlavey and Fred Van Lente. All rights reserved. Reproduced with permission)

It is rather common knowledge that the self-serving “expert practitioner” designation is basically a sort of ego-massaging. An interesting view concerning “expertise” was expressed by the *Baltimore Sun* columnist Roger Simon: “William Bennett, who had been secretary of education without solving the problems of education and drug czar without solving the problems of drugs, now wants to write a book on how to solve the problems of both. In America, this is what we call expertise.” In this respect, one can find many examples of the “tool becomes the agent” metaphor. Some of them have already been discussed in various parts of the book. In several other cases, the tools lack creativity and innovation, merely repeating trivial ideas, often deprived of any objective grounding in principles of critical reasoning, human value, and vision. For example, a plethora of computational models for environmental assessment purposes have been developed irregularly and routinely sprawled along the way to the funding agencies, without any coordination and interaction, notably lacking in intellectual rigor, insight, and aesthetics. The main motivation for this sprawling of computational models often is to satisfy the self-esteem of their developers and attract research funds.[2] The chaos that rules much of computational sciences nowadays is the inevitable result of this culture. A culture characterized by its unwillingness to examine issues of axiological meaning, intellectual purpose, and moral justification about one’s beliefs and actions; and which must realize the fact that computers may have an unbreakable speed limit, which imposes certain limits on possible improvements of computational models.

9.2.4 George Bernard Shaw’s Apple and Scientific Software

George Bernard Shaw once said, “If you have an apple and I have an apple and we exchange these apples, then you and I will still have one apple. But if you have an idea and I have an idea and we exchange these ideas, then each of us will have two ideas.” Unfortunately, the exchange of ideas is often not possible in the corporatism era when everything is copyrighted and has a material price decided by clerks and managers. As a matter of fact, an increasing number of people argue that software programs based on scientific computational models and data processing techniques should become “open-source,” especially when the projects that led to the development of the software were supported with public funds. Currently a large proportion of this software remains “closed-source,” which means that outsiders cannot test its validity and accuracy in an objective, rigorous, and systematic manner. Although nobody is surprised about the restrictions (closedness is often one way to avoid exposing a mediocre piece of work), critics have argued that this situation violates a fundamental principle of scientific inquiry. Noticeably, if the practice of computational sciences was followed in experimental sciences, the repeatability of one’s experiments should not be a prime prerequisite for accepting the validity of their

[2] Hopefully, in the process they may also satisfy the social goal of reducing PhD unemployment.

outcomes. Similarly, in pure mathematics one would claim that has proved the most difficult theorems without being required to present detailed proofs.[3]

There is another side in this debate. The needs of data processing in various disciplines sometimes have led to the uncritical implementation of commercial software or software developed by researchers with a specific project in mind. It should not escapes one's attention that software implementation should involve essentially the entire methodology that has been established for physical experiments and refers to issues of replicability, stability, control testing, portability, and error tracking. Alas, often this is not the case. As we will see in Section 9.4, the "brute-force" implementation of statistics software in public health sciences has led to a number of serious problems. In an effort to resolve some of the relevant issues, Roger D. Peng (2006b) suggested: "In addition to providing computer code, or instructions for data analysis, authors must also explain how the computer code is linked to the data and which code sections apply to which data."[4] At first glance, this suggestion seems to make sense, but experience tells us to be cautious when it comes to the practical value of similar suggestions. For one thing, the use of research software codes by people who did not develop them is not always without difficulties. Indeed, a significant percentage of the research software is ad hoc and sometimes suffers from what computer engineers call "kludge," i.e., codes that wind up full of useless complexity that is incomprehensible even to those who wrote them. Also, one should not forget the so-called "program rot," i.e., the investigators who wrote the software move on and the machines change, often leaving the software in a state of dysfunctionality. Furthermore, the uninitiated may not be aware of the fact that many of the software codes seem to conveniently invent the future rather than try to predict it. Another issue is the fact that the number of ways in which software computations can get the wrong results are practically inexhaustible, so that it is nearly impossible to discriminate between the results of rival software calculations that fail to agree. Not to mention that when one has to select between rival techniques and associated software codes often selects the technique and code that gives results in agreement with one's belief system. In a rather typical case, Kwang-Hua W. Chu (2008) argued that the approximate techniques of Bahraminasab et al. (2007) are valid only for low-frequency regimes. Unsurprisingly, Bahraminasab et al. (2008) responded that, "Chu's arguments and objections against our previous results are invalid." And the life goes on. Be all that it may, genuine interdisciplinarity could

[3] A repudiated "closed-source" version of a mathematical proof was presented by the seventh-century French mathematician Pierre de Fermat, who wrote a note in the margin of his book claiming that he had proved a celebrated Conjecture, but supposedly there was not enough room in the book to describe his proof. It took more than 300 years for a real proof to be finally provided by Andrew Wiles. Naturally, Wiles' proof was "open-source" involving several calculations and knowledge not available in Fermat's time; and it underwent various stages (e.g., an error in Wiles' original calculations was discovered by other mathematicians, which was subsequently corrected by him, who eventually went on to achieve his life's ambition to prove the famous Fermat Conjecture).

[4] See, also, press release of Johns Hopkins Bloomberg School of Public Health (March 8, 2006): http://www.jhsph.edu/publichealthnews/press_releases/2006/peng_reproducibility.html

offer a way out of this mess by establishing an IPS culture based on open exchange of ideas, intersubjectivity, mutual trust, respect and exploration.

9.3 Yet Another Look at IPS

In the following I will revisit certain IPS aspects under the light of the multidimensional conceptual framework discussed in the previous chapters. From a certain perspective, problem-solving is a threefold affair: Experiencing life directly, learning from the experience of others, and interacting with different manifestations of available knowledge (reading books, searching the Internet, etc.). Each one of these aspects has its own individual merits, which are considerably enhanced through their imaginative synthesis during the IPS process.

9.3.1 Thoth's Technology and Tammuz's Critical Thinking

At the end of his dialogue *Phaedrus*, Plato tells the story of Thoth and Tammuz. The Egyptian god Thoth, founder of the arts, is the inventor, amongst other things, of *writing*. He takes his invention to Tammuz, the king of gods. Thoth addresses Tammuz by saying (Hamilton and Cairns 1961: 520): "Here, O King, is a branch of learning that will make the people of Egypt wiser and improve their memories: my discovery provides a recipe for memory and wisdom." However, king Tammuz scolds Thoth roundly: "If men learn this, it will implant forgetfulness in their souls; they will cease to exercise memory because they rely on that which is written, calling things to remembrance no longer from within themselves, but by means of external marks. What you have discovered is a recipe not for memory, but for reminder." This dramatic dialogue represents the struggle between two main contributors of human progress. On the one hand, Thoth presents writing as a new and powerful cognitive technology. Throughout time, such technologies have liberated the mind from the necessity of carrying a large number of details and facts. By allowing the storage of knowledge outside the mind, it becomes possible to divert valuable cognitive energy to more complex thought processes (Mioduser 2005). Tammuz, on the other hand, argues in favor of deep thought and introspection, noticing that, "by telling them [the people] of many things without teaching them, you will make them seem to know much, while for the most part they know nothing." Tammuz's critical perspective essentially foreshadows the dangers involved in relegating a growing number of mental functions to technology, which could lead to degeneration of human cognition and critical thinking. In the end, the above dialogue demonstrates that the interaction between human reasoning and cognitive technologies can become a fascinating field for inquiry and reflection, both of which are invaluable aspects of a creative IPS.

Surely, one cannot emphasize enough the significance of critical thinking that is generally viewed as the combination of (Gabennesch 2006) rational skills based on higher-order cognitive operations involved in obtaining, processing, and communicating knowledge; skepticism, since things in the world often are not what they seem to be; and high values of principled individuals (ethically committed to the intellectual due process, and accounting for important aspects of social life). The indispensable role that Epibraimatics assigns to critical thinking is evident throughout the book. Yet, is critical thinking becoming a rare quality in human inquiry? Warren G. Bennis speculated that "[t]he factory of the future will have only two employees, a man and a dog. The man will be there to feed the dog. The dog will be there to keep the man from touching the equipment." Are humans really becoming more and more irrelevant in a machine dominated world, so that Bennis's imagination is a real possibility in our future? Let us hope that this is not the case, and that humanity will find a way out of similar nightmare scenarios. The take-home lesson, however, is that modern-era problem-solving requires the conjunction of different modes of critical thinking, and their temporal phasing and spatial integration in the light of sound science and creative methodological inquiry, thus leading to the derivation of effective and meaningful solutions in an multidisciplinary in situ environment. Within this framework, critical thinkers are secure in their sense of self, and do not mistake changes in viewpoints as changes in the health of their souls and psyches. They have a strong sense of group connectivity and have learned that change, even radical, need not be a crisis in self-esteem.

9.3.2 Bella Gerant Alii, Tu, Felix Austria, Nube[5]

At the risk to disappoint some ahistorical postmodernists, I will once more resort to history in order to make my case. Since the late Middle Ages the Austrian Habsburgs had adopted an unconventional yet creative thinking mode concerning matters of territory expansion: gaining new territories by means of successful marriages rather than in the traditional way of war campaigns. Famous became the motto of the time: *Bella gerant alii, tu, felix Austria, nube!*[6] The Habsburg dynasty is an example of what is called "thinking outside the box." It is the sort of creative thinking that challenges the established way of doing things in a variety of unexpected ways; it often looks at and does things in a different manner; and it proposes something that is new and valuable at the same time.

"I shut my eyes in order to see," the great Paul Gauguin once said. This could very well be one of the slogans of the emerging *Conceptual Age*. In order for the world of scientific innovation to succeed, it needs to go beyond critical reasoning into the realm of creative thinking and imagination. The creative approach to problem-solving is both powerful and distinctive. The investigator should be intrigued rather than dismayed by apparent contradictions, whether they consist

[5] Wars may be led by others, you, happy Austria, marry!

[6] The readers may detect a certain resemblance between the Habsburgian motto and the slogan of the American counterculture of the 1960s, "Make love, no war!"

of experimental results that conflict with theoretical predictions or theories with formal inconsistencies. Creative thinking does not set up and follow routine patterns, but produces new solutions and unexpected results, and also creates new values. The need for creativity in IPS stems from the fact that, even if the world is ontologically unitary, our knowledge of it is epistemically diverse.[7] The gist of the whole business then is that only by interpolating between the full range of different disciplines in an environment of balanced critical and creative thinking, an investigator can arrive at a satisfactory account of problem-solving. In the globalization era, it is this kind of interpolation that can make the big difference. Yet another feature of the globalization era is the postmodern way of life. Postmodernism is what Glenn Ward plausibly characterized a "portable" term, lacking a universally accepted definition (Ward 2003). In the Conceptual Age, the term will continue to have a range of potential meanings and applications. However slippery and contradictory it may be,[8] postmodernism could offer a way into debates about thinking modes, belief systems, lifestyles, and cultures, which is why certain parts of the present book have a postmodern flavor, whereas several others are critical of radical postmodernism.

9.3.3 Other Aspects of Problem-Solving

Beyond the rigorous presentation of mathematical IPS operators (e.g., Chapter 7), an attempt should be made to communicate these results, with their full technical beauty, across disciplines. The analysis and interpretation involved in real-world case studies can teach an investigator many things. Such studies can show, e.g., that one should not underestimate the importance of finding a suitable problem to solve, which can turn out to be the most difficult part of the investigation process. The artistry and innovativeness of sound research often consists in finding problems that scientists know that they can solve and the appropriate methods for their solution.

9.3.3.1 Polishing Existing Apples and Building Castles in the Air

A sound problem-solution should demonstrate original thinking about the problem, and lead to substantive and previously unexpected results. For example, Mark I. Shvidler's pioneering research on heterogeneous media flow (Shvidler 1962, 1964, 1965) presented with rigor and clarity new ideas and original insights concerning the underlying physical processes, which is why Shvidler's ideas have affected considerably the work of many researchers in the field, whether they are willing to admit it or not. As a matter of fact, one finds many distinguished scientists who have produced

[7] Due to technological, personal, cultural, and historical constrains.

[8] This is particularly true for certain types of radical postmodernism (Section 8.4.2).

highly innovative research results that have gone largely unrecognized. Instead, they have been sometimes unfairly criticized and even belittled by mediocre minds for not following the beaten path in research. The fate of these pioneers fits Lyndon B. Johnson's observation: "If one morning I walked on top of the water across the Potomac river, the headline that afternoon would read 'President Can't Swim'."

Many investigators follow the beaten path in research so that they can have carefree lives frolicking in their fields of expertise. They seem to have convinced themselves that this is the "real-world of adults," where one must learn to keep one's head down and try not to think so much about the profound injustice and opportunism that characterize their disciplines. On occasion, the same investigators may adopt a complex technical (hermetic) jargon because they believe that they can publish easier, but in the end this frame of mind leads to research findings that are commonsensical, lacking any kind of substantive novelty. Some of the readers may be familiar with Waldo Tobler's first law of geography: "Everything is related to everything else, but near things are more related than distant things" (Tobler 1970). Similarly, porous-media studies have produced a number of supposedly new findings like, "under-prediction increases with an increase in the disorder . . . and a decrease in the spatial correlation" (Lu and Yortsos 2005: 1279). This kind of "laws" and findings come as no surprise to any expert , or even non-expert yet rational individual; they are mere trivialities at least as far as the current state of knowledge is concerned. Metaphorically speaking, a considerable part of current research in certain disciplines is simply about polishing an existing apple to a (hopefully) brighter shine. Serious contributors to scientific inquiry are those investigators who are able to look in new and innovative ways at the data that are available to everyone. Moreover, problem-formulation should be made in a way that does not obscure the real issues of the study by piling up irrelevancies around them. This is a lesson to be learned from the controversial studies of environmental pollution and health effects following the WTC collapse (Lioy et al. 2002; Lioy 2006). The matter has been discussed extensively (see, also, Section 2.5.1). At the heart of the problem is that it is difficult to reconcile a plausible account of what is involved in the truth of the WTC exposure results with a credible account of how the investigators came to obtain these results. Many scholars have argued that this is the sort of environmental research that builds "castles in the air." It may contain a special kind of "private" logic of its own, but is otherwise disconnected from real events and mostly irrelevant to the human exposure issues it is supposed to address. Lastly, a recent book on global oil crisis (Gorelick, 2010) is a typical demonstration of how an interdisciplinary study should not be carried out. The book presents neither a deep analysis of the issues nor a rigorous synthesis of scientific views and uncertain knowledge bases from different disciplines (geoscience, economics, history, politics etc.). Instead, its arguments are mostly irrelevant to the basic thrust of the global problem, and the book's strong views are based on highly questionable interpretations of the facts (concerning the widespread prediction that increasing use of petroleum will deplete the supply in the foreseeable future etc.). If one wonders why critics sneer at experts for firing before they aim, this book offers a good answer. In a time of Decadence, behaviors of this kind are fast approaching a societal norm that can be destructive to both scientific inquiry and the public's welfare.

9.3.3.2 Integrative Problem-Solving in War Zones

Ultimately, a serious study should assess whether the selected solution process institutes a broad methodology in which different sets of entities (theories, techniques, thinking styles) describing constituent phenomena in the individual disciplines can be integrated to study (describe, explain, and predict) the in situ problem. The importance of multidisciplinary IPS thinking is demonstrated in recent case studies of the US military strategy in Iraq and Afghanistan (Storlie 2008). The change of course was that instead of USA and its allies measuring success solely in terms of military indicators (such as the number of insurgents killed), they started also considering different kind of multithematic indicators that measure the local populations' unemployment level, access to basic services, sense of safety, etc. As it turned out, such economic, political, and social indicators, together with the military ones, can help decision-makers obtain an integrated assessment concerning the effectiveness of a military strategy in each region of the country.

9.3.3.3 The Victorious Romans, Black Death, and Monkey Drowning

Naturally, at the center of a real-world case study is the available empirical evidence – data and facts (Will 1993; Sivia 1996; Christakos and Li 1998; Vyas et al. 2004). To a considerable extent, what makes a case study a real one and not, say, a simulation, is the use of these real data and facts. Having said that, the following observations have been made in various parts of the book: (a) One can never be absolutely certain of what one is given. When data are generated by the investigator's sense instruments, different instruments may give contradictory information.[9] (b) One may distinguish between epistemic observation and ontic observation. The latter observation involves the eyes' retinas physically receiving the light rays reflected on an entity's surface, but not mentally processing them so that the agent becomes conscious of the entity; whereas the former observation involves conscious processing and interpretation. (c) The value of a dataset should be judged by its capacity to contribute toward a meaningful and well-structured whole. This whole should be free of inconsistencies among the different data sources as well as conflicts between data and the underlying theories. (d) Data are necessary but not sufficient, and scientific inquiry involves a continuous dialogue between theorists and experimentalists. The investigator is central to this dialogue, which is sometimes constructive and mutually beneficial, and some other times it is confrontational and dead-ending.[10] (e) Many case studies rely on data analysis software that forms the

[9] Consider, e.g., the elementary case of a stick submerged in the water; the sight of the agent's eyes suggests that the stick is bent, whereas the touch of the agent's hands suggests that the stick is straight.

[10] It is not unusual that an investigator favors the kind of data that suit a specific cause and ignores others; or one interprets the meaning of the available facts in a way that serves a specific worldview; or one neglects to ask the right questions in order to obtain the necessary data and facts.

basis of decision making and planning. This sort of analysis often stagnates in old conceptual frameworks that routinely look at the data in only one way, lacking creative speculation and the consideration of alternatives.

For all these reasons, the multiperspective and, when appropriate, multidisciplinary consideration of the data can play a crucial role in real-world studies. It is not unusual that, like dress patterns, the data are tailored to suit the specific needs of the people who analyze them. In many case studies vital data are hidden, partially recoverable, or can be interpreted in more than one way, which can affect decisively the final analysis. In history, e.g., the winners often go out of their way to keep the tightest control on all data concerning events of their time. Famous is the case of the ancient Carthage: following their obliteration of Carthage, the Romans, brutally pragmatic as ever, deliberately destroyed all relevant records kept by their enemies. Hence, all the available databases about Carthage derive from the Romans and their collaborators. Similar is the case in social sciences. According to Danny Dorling and coworkers, changes in the spatial and temporal scales of the data can lead to very different conclusions about important social indicators. In particular, the indicators of the parliamentary constituencies in England have been reported in a way that (Dorling et al. 2002), "[i]f an indicator had not improved for one timescale then the timescale was changed for that constituency to one during which conditions had improved. Indicators are also reported at different spatial scales. If conditions hadn't improved at the constituency scale, for example, then a larger scale was deployed at which things had improved."

The debate concerning the etiology of Black Death in fourteenth-century Europe involves a considerable disagreement about what the available evidence is and how to interpret the data. Most experts agree that in their current form, archeological DNA data can be notoriously unreliable (Bryson 2003; Gilbert et al. 2005). Nevertheless, these kind of data have been used repeatedly in the epidemic etiology debate. One can find in the general literature several studies based on unreliable data, the main goal of which is to influence public opinion (seeking to promote a certain ideology, support a political agenda, increase the funding of a research field, etc.). It is not an unusual phenomenon in today's culture that eye-catching stories of supposedly new and important health research findings marvelously appear in the newspapers, but like summer storms they come and go in a flash, without settling. Such are the extremes that an increasing number of research studies reach in their effort to shock feeling and provoke emotion, that they could be properly represented by the metaphor showing a man's resentment of his mother-in-law by the symbolic yet extreme act of drowning a monkey.

9.3.3.4 Try, Fail, Try Again, Fail Better

In many in situ situations problem-solving is, to a considerable extent, a *feedback process*. That is, an initial solution is obtained, which is subsequently improved – often more than one time – until a satisfactory state is achieved. From an Epibraimatics' perspective, a key element of pathfinding IPS is that any pursuit that goes beyond what is currently known is not a progression that follows a preestablished order. One of the most accurate representations of in situ problem-solving is probably the following quote by Samuel Beckett: "Try, fail, try again, fail better." The readers would find it intriguing that Beckett's quote applies, in a spectacular way, in the case of Dietrich Hrabak, a German pilot who was shot down on the very first day of the Second World War, but went on to score 125 air-to-air victories for Luftwaffe. All kinds of problem-solvers might find considerable inspiration in the case of Hrabak. In the same context, investigators should learn to tolerate approximations, and be able to appreciate that even solutions based on approximations can offer valuable knowledge. Those who seek to set up a solution process characterized by absolute order and precision are not likely to get very far in real-world problem solving. There will always be unproven assumptions or technical issues that cannot be resolved immediately, but the important thing is to keep pushing forward. Insisting that every step of the IPS process must be absolutely irrefutable, is a recipe for going nowhere in a reasonable amount of time.

From experience an investigator knows that, before implementing any software package in situ, it is advisable to investigate the problem adequately – to calculate the order of magnitude of the attributes of interest, and to find out as much as possible about the general behavior of the solution. Also, experience has shown that it is beneficial to cultivate one's intuition about how to treat this or that term in an analytical equation, using numerical methods. An investigator should by no means underestimate how much one does not know. In some cases, it is difficult to know whether two different software packages really model the same system, since scientists may be not always aware of the implications of certain modeling choices they have themselves made. As noted earlier, an adequate software library should provide the means to test empirically certain results of the analysis, but it should also acknowledge that verificationism is not the whole story. Indeed, many important entities (like the theoretical particles of physics) are inferred rather than empirically observed, and certain natural laws cannot be derived from empirical analysis (like the law of inertia). In addition, software developers and users should not undervalue the fact that many people may have a stake in the phenomenon under study (e.g., this may be the case with cancer research and global warming effects).

9.4 Marketplace of Ideas, and Tales of Misapplied Statistics

As was mentioned in Section 2.2.8, much of mainstream statistics is Lockean, producing PDD solutions that do not escape the fatal confounding of sense knowledge with intellectual knowledge. The result is often an agglomeration of conflicting theories and internally inconsistent techniques. When it comes to accounting for uncertainty in real-world situations, several PDD studies place all emphasis on technical matters, neglecting to check the epistemic underpinnings and physical basis of the situation. In many cases, this neglect leads to "quick and dirty"

Table 9.1 Items of concern about statistical modeling

1. Overreliance on the "let the data speak" doctrine, and underappreciation of the importance of the fruitful interplay of technical mastery and physical understanding	2. Uncertainty introduced by models is larger than the original uncertainty of the dataset
3. Neglect of the real in favor of the symbolic and elusive (often confusing an entity's name and the entity itself)	4. Statistical hypotheses mistaken for scientific hypotheses when, at the same time, the overall physical picture remains in the background
5. Internal inconsistency of the reasoning mode underlying the "quick and dirty" techniques	6. Excessive use of simplistic statistical hypotheses (normality, linearity, independency, etc.). Statistical simplicity does not necessarily accord with physical simplicity
7. PDD regression models improperly attributed a fundamentality level comparable to that of physical laws	8. Counterfactual claims concealing the infeasibility of a statistical study and diverting attention from the real issues

techniques with serious consequences that could undermine the validity of the generated results and their societal value.

This problematic situation has characterized much of statistical modeling in health sciences (clinical research, environmental exposure, public health, and epidemiology). By now it has become clear that the modeling inadequacy is due to a variety of interconnected items, such as those listed in Table 9.1 (most of these items have been discussed in previous sections of the book). Plato thought that the gulf between ideas and life could be always bridged by dialogue. Not only by written dialogue, which is often a superficial account of past events, according to Plato, but primarily by a real, spoken exchange between people of different backgrounds. Accordingly, a reasonable suggestion would be that the resolution of statistical modeling issues requires an interdisciplinary dialogue. This means that the various disciplines should willingly enter into the *marketplace of ideas*, where diverging viewpoints are debated, and their relative merits evaluated by means of rational reasoning. A key challenge for the marketplace of ideas would be that the different scientific disciplines eliminate any hermetic jargon (as a way to defend barriers), and make explicit the underlying paradigms so that they can be subjected to scholarly scrutiny.

When it comes to many health statisticians the ancient motto applies: *Ου με πείσεις, καν με πείσεις*, i.e., you will not convince me even if you do convince me. Many scientists believe that statisticians are not willing to enter the marketplace of ideas, for the simple reason that they do not risk falsification in their intellectual exchanges. Perhaps, their concern is that they may have the fate of Pyrrho of Elis, who once got so irritated by public questioning that he stripped off his clothes, leaped into the nearby river Alpheus (Αλφειός), and swam away. In any case, the result of the above risk-free attitude is what Jürgen Habermas has called an "embrace of irrationality," in which "any objective truth-claim is dismissed in favor of a multitude of 'narratives'."

9.4.1 The "Let the Data Speak" Mindset and the PDD Doctrine

According to the distinguished epidemiologist Sander Greenland (1989: 340), "Statistical modeling may be defined as using the data to select an explicit mathematical model for the data-generating process." The unconditional reliance of much of applied statistics on the "let the data speak" doctrine ("data-massaging" might be closer the mark in many cases) ignores the contentual and contextual features of these data. Joseph Stalin was well aware of statistics' disregard of substantive content when he declared, "A single death is a tragedy, a million deaths is merely a statistic."

9.4.1.1 The Brain-Numbing Era

The PDD mindset has a distinct dehumanizing effect. The human being plays a rather small role in the process, all that matter is mechanical data-fitting. No priority is given to context and content, and no substantive theories or scientific models are needed for PDD analysis. All one has to do is to listen carefully to Chris Anderson, one of the preachers of the Petabyte Age: "We can stop looking for models. We can analyze the data without hypotheses about what it might show. We can throw the numbers into the biggest computing clusters the world has ever seen and let statistical algorithms find patterns where science cannot;" and "[t]he new availability of huge amounts of data, along with the statistical tools to crunch these numbers, offers a whole new way of understanding the world. Correlation supersedes causation, and science can advance even without coherent models, unified theories, or really any mechanistic explanation at all."[11] Welcome to what could easily turn out to be the greatest *Brain-numbing era* of all times.

Real-world experience shows that among the many important things neglected by Anderson's thinking mode is that, the more facts one has, the easier it is to put them together wrong using a PDD technique. A similar argument has been put forward by Bobby Ghosh in a national security context. He maintained that the main reason that the information dots were not properly connected by NCTC's[12] experts in the case of the attempted Detroit bombing (Christmas Day of 2009) is that (Ghosh 2010: 20) "[t]here are too many dots [data]." Richard Bookstaber argued that it is not the lack of data that is often the main problem; instead, too much information is the real problem. He describes the case of trading where (Bookstaber 2007: 226) "the more information we extract to divine the behavior of traders . . . the more traders will alter their behavior." Yet another fundamental fact that escapes Anderson's attention when he suggests to "let statistical

[11] Perhaps, Anderson would like to reconsider his views, if not on intellectual grounds, at least in light of the fact (Schenkman 2009) that computers have an unbreakable speed limit that imposes strict limits on the efficient "crunching" of huge amounts of data (see, Section 3.6.1).

[12] U.S. National Counterterrorism Center.

$$S=\{\chi_t : t=1,\ldots,100\} \xrightarrow{PDD\ Models} \begin{cases} \text{Pattern (regularity) 1: } \chi_t = t \\ \text{Pattern (regularity) 2: } \chi_t = \prod_{i=1}^{100}(t-i)+t \end{cases}$$

$$\xrightarrow[at\ t=101]{Prediction} \begin{cases} \hat{\chi}_{101} = 101 \\ \hat{\chi}_{101} = \prod_{i=1}^{100}(101-i)+101 >> 101 \end{cases}$$

Fig. 9.3 An illustration of a methodological difficulty of PDD analysis

algorithms find patterns," is that there are many patterns that fit any given dataset,[13] in which case a technique is useless, unless it can determine which pattern, among the many, represents the underlying phenomenon. Let us consider a simple yet illustrative example (Fig. 9.3). Two very different PDD patterns (regularities) fit the available dataset S ($t = 1, \ldots, 100$) perfectly. But when these patterns are used to make a prediction at $t = 101$, they give very different predictions ($\hat{\chi}_{101}$ values). Hence, the obvious question is which PDD pattern (regularity) should be used for prediction. Since it does not provide a clear answer to such fundamental questions, the PDD mindset is problematic in real-world applications and, on occasion, it has been linked to disastrous situations, such as the case of record events that occur beyond past experience (e.g., a flood; Shelby 2004). Furthermore, the specific pattern of the phenomenon revealed by the existing data may not repeat itself in the future, i.e., the phenomenon's pattern may evolve. In fact, many phenomena of this kind exist in Nature. According to Kauffman (2008: 123), "at the level of the evolution of species, of human economy, and human culture … the universe is vastly not repeatable," and, hence, unpredictable in terms of PDD techniques.

The above methodological problems of the PDD techniques are due, to a considerable extent, to the fact that they rely on the rather naive characterization of induction as a system that projects observed data patterns (regularities) in the future.[14] However, this way of thinking is pointless, unless one can say *which* regularities the PDD approach projects. In a similar vein, the statement that pure induction presupposes the uniformity of Nature is equally pointless, unless one is able to say in *what* respects Nature is presupposed to be uniform. Accordingly, the riddle for PDD statistics is to specify a set of substantive rules that can be used to determine which regularities are projectable. Until this is done, the serious problems associated with the uncritical use of PDD techniques in statistics, geostatistics, data engineering, and machine learning (Han et al. 1993; Cherkassky and Mulier 1998; Chiles and Delfiner 1999; Schölkopf and Smola 2002; Bishop 2006) will remain unresolved.

[13] This is also known as the *indetermination* thesis.

[14] The inadequacy of pure inductive reasoning underlying PDD analysis was discussed in Section 5.2.1.

Nonetheless, in a "politically correct" spirit the PDD devotees are quick to argue that the pseudo-dehumanization element of the brain-numbing era is actually a sign of "democratization" of the research process: anyone with some basic technical skills (yet lacking substantive knowledge) is invited to use the PDD software interactively and efficiently. A sensible scientist's response to the PDD invitation would be in Napoleonic terms: *Not tonight, Josephine*. A justifiable response, indeed, if one realizes the real danger that an investigator's chance to experience oneself and the real-world can be effectively cut off by the uninspiring PDD culture. A well-known example is the case of the human exposure project described next.

9.4.1.2 PDD Versus Science-Based Statistics

To many statisticians PDD analysis is almost like a second nature. "We propose to avoid the cumbersome task of specifying a prior density…and let the data speak themselves." (Piltz et al. 2005: 58). Similarly, "the first step of data analysis is to let the data speak for itself" (Benestad 2002; 107). On the other hand, scientists have criticized PDD techniques that project observed data patterns in the future but "have little or no physical basis, serving only to 'let the data speak for themselves" (Clarke 2002). Surely, the neglect of physical fidelity and basic epistemic principles cannot be without consequence. Many applied statistics tests entail serious logical problems, and are often irrelevant to the objectives of the in situ study; the science of space and time are not taken into consideration; and rigorous mechanisms are lacking to incorporate substantive knowledge (parameterizations are physically unstable, model selection deweights relevant evidence, etc.). This is aided by an excessive use of data-crunching schemes, and a heavy reliance on "black-box" software from different sources. For example, "few epidemiologists will employ methods not available in the leading software packages" (Greenland, 2001: 663). In essence, the PDD mindset represents the defeat of creative act and originality by trivial habit. To use a metaphor, the whole affair reminds someone who is interested to count *all* the seeds in an apple but not to predict all the apples that would come out of *one* seed.

Without doubt, many of these problems could have been pointed out by scientists from different disciplines participating in the marketplace of ideas, assuming that the latter was a viable possibility. Obviously, a discipline considers truth what it understands – on the basis of its current conceptual and technical arsenal. But this truth may change drastically when exposed to the combined effect of the arsenals of other disciplines viewing the problem from different angles. For the sake of argument, consider the great Ludwig Boltzmann who was responsible for some of the most significant achievements of classical physics. Instead of merely collecting and processing large amounts of experimental data showing that a heated gas expands, Boltzmann's contribution to the marketplace of ideas of his time was to develop an elaborate atomic theory that allowed him to explain scientifically why a gas expands, and by how much. Atomic theory provided a more complete, encompassing, and intellectually satisfying account of the real phenomenon rather than a set of regularities deduced by data processing but left unexplained (like those in Fig. 9.3). A representative case of the problematic PDD mindset is the air pollution health effect project (herein, APHE; Samet et al. 2000a, b, c; Zeger et al. 2000). The strategy of the project was to rush the use of a maze of statistics techniques and schemes in the study of air pollution and health data, but without either an adequate understanding of the underlying theory or a satisfactory account of the content- and context-dependence of the relevant datasets. The APHE statistics models might make sense when considered individually and as isolated technical components, but their interrelations are not at all obvious in the in situ setting, or they relate mostly to situations lacking any scientific subtlety. Although structural breaks in the air pollution data can make them noncomparable across different space–time domains, these breaks are not detectable on the basis of technical data-driven analysis alone. Also, the uncertainty introduced by the complicated APHE statistical models is often larger than the original uncertainty of the dataset itself. Methodologically, the APHE project had several other problems: it was organized and functioned around an absolute tool-like rationality; a severe self-reference problem (turning data regression into a regress loop, see Section 9.4.3 below); reality was sacrificed for simplicity; its analysis was theoretically overdetermined and yet empirically underdetermined; and its neglect of the importance of the extra-data factors (since many models would agree equally well with the given dataset, the model selection must be based on something else than data; see extra-data factors, Section 8.2.2). The APHE project ignored the above fundamental scientific and methodological issues. And as usually happens in such cases, the consequences were twofold: given the degree of complexity and interconnectedness of human exposure phenomena, the project's best tools proved to be its worst instruments; and the project basically relied on a "brute force" implementation of statistical software packages, untested and disturbingly unfit for the task at hand. As we will see next, this twofold strategy led to severe health assessment problems.

9.4.1.3 Liberated Through Submission

In view of the above and similar considerations, it is hardly surprising that the APHE project eventually led to inaccurate health effect estimates that have shaken scientists and policy makers. During 2002, articles in *New York Times*, *Science* and *Nature* seriously questioned the credibility of the entire project, and its potential impact on public health assessment (Knight 2002; Kaiser 2002; Revkin 2002). According to Knight (2002: 677), "A default setting that produced erroneous results went unchecked for years . . . the error had doubled her group estimates of the risk to health posed by particulates in the air." Knight also quotes Francesca Dominici's[15]

[15] A member of the APHE group.

explanation: “It was already such standard software when we started using it, I didn’t even question it.” This explanation is remarkably consistent with the “liberated through submission” outlook of certain academic circles.

A variety of plausible scenarios were suggested concerning the main causes of the APHE’s misfortunes, ranging from the theoretical to the commonsensical. Lumley and Sheppard (2003: 13) noticed the importance of an in-depth understanding of the theory behind a technique: “A precise understanding of what goes wrong requires knowledge of the underlying mathematics.” Kaiser (2002: 1945) came to the obvious conclusion: “The experience also serves as a cautionary tale to scientists who use off-the-shelf statistics software without questioning what’s inside.” David Smith, manager of the company that sells the commercial statistics software used by the APHE group, said the obvious: “Users should always check whether changing the parameter affects the outcome, and adjust it if necessary” (Knight 2002: 677). Referring to the particular case, Lumley and Sheppard (2003: 13–14) suggested that “[i]n the absence of expert assistance, epidemiologists should identify whether the method is standard. It is not sufficient that there is a single widely used implementation of a method or that it has become standard in one narrow field. This narrow view of accepted practice is one of the reasons why, well before their limitations were uncovered, GAMs[16] became so widely used in air pollution epidemiology.” No doubt, the danger associated with the “black-box” implementation of software by nonexperts is rather obvious. Beyond these technical matters, perhaps more important is the fact that no sufficient attention was paid to the content and context of the data (including the possibility that uncritical use of “standard” software often hides all sorts of fine tuning that may affect data interpretation and fails to recognize crucial associations between statistical parameters and scientific evidence), and, as a result, the group could not suspect that something was wrong with the APHE estimates. This reveals in all its crassness what has long been true of the field: critical thinking has become the ideology of its own absence.

One must always remember that organized groups busy making deals and exchanging favors do not drink deeply from the river of knowledge, they only gargle. When it comes to health statistics modeling, for a long time “Nearly everyone finds it convenient to employ ‘off-the-self’ model forms, i.e., whatever is available in packaged computer programs” (Greenland, 1989: 341). Despite sound warnings, the heavy reliance of health research on “of-the-self” software continues uninterrupted. This is probably based on the logic of combining complicated statistical techniques with the minimum implementation effort. Indeed, too many software packages have been developed (statistical, geostatistical, and GIS) and widely used that focus on ease of implementation and mechanization of things, whereas matters of substantive knowledge, scientific methodology, logical coherence, and internal consistency are emphatically ignored. It is rather disturbing that many pseudo-practical software packages

[16] Many time-series-based studies in air pollution and epidemiology used the GAM (generalized additive models) function of S-Plus.

consider as the ultimate advertising slogan that the user does not need to know the theory in order to use the software. This is a logic that brings to mind the metaphor of decaffeinated coffee: get the pleasurable result with a minimum of side effects.[17] It is a sign of the times, that this calamity could have been easily averted if an interdisciplinary marketplace of ideas had been established by those responsible (including scientific associations, funding agencies, and higher education institutes). On the contrary, untouched and undisturbed by previous failures, the cabal continues its effort to reach the ultimate goal of transforming itself into a "virtual software" that can reload itself from one hardware to another.

9.4.2 Neglect of the Real

Noticeable is statistics' occasional neglect of the real in favor of the symbolic and elusive, which brings to mind Lacanian film theorists (Walsh 1994). It is instructive to follow the reasoning of statistical causal inference (Rubin 2007: 33): "It is the quality of the assumptions that matters, not their existence or even their absolute correctness." This is yet another case of "private use of reason" at its purest. One is initially astonished by the claim that being correct and physically realizable are not among the desirable qualities of an assumption. Otherwise said, it does not really matter if an assumption is incorrect and inexistent (having nothing to do with the real-world phenomenon it is supposed to represent). What counts is that the assumption has the elusive features that, on occasion, the modeler may find convenient. Beyond these radically postmodern claims that defeat rational thought, with a single strike Rubin's analysis did away with the basics of scientific inquiry that for an assumption to be valuable, it must survive the test of time in countless engagements with existing reality. The readers are reminded of a similar truth-neglecting doctrine proposed by Cherkassky and Mulier in Section 8.2.2: "Limiting model complexity is more important than using true assumptions."[18] There is something infinitely saddening in that some researchers find ways to diminish the value of truth. It is of some consolation that an increasing number of thinkers react to this sad state of affairs. For example, the neglect of the real has been pointed out in Richard Smith's criticism of human exposure statistics (Smith 2003: 1067): "Dominici et al. say that this 'does not complicate our inferences' (Dominici et al. 2003a: 1064), noting, in particular, that the backward-time component of

[17] It goes without saying that serious coffee-drinkers will not agree with this logic, they will just dismiss it as a fake.

[18] Reading the previous statements the readers may hear the echo of Timothy's prophecy: "For the time will come when they will not endure sound doctrine; but after their own lusts shall they heap to themselves teachers, having itching ears; and they shall turn away their ears from the truth, and shall be turned unto fables" (II Timothy 4:3–4).

the effect is not physically realistic and therefore presumably can be ignored in the interpretation. I am far from convinced: Does it really make sense to build a regression model that forces the inclusion of physically unrealistic components? . . . In the present context, it seems to me that adoption of an unrealistic model could both bias the regression coefficients and increase their standard errors to an unacceptable extent." Indeed, many exposure studies fail to appreciate the importance of an irreducible tension between theory and practice: theory is not just the conceptual grounding of practice, it simultaneously accounts for why practice is ultimately doomed to failure. Some readers may agree that T.S. Eliot's observation applies equally well here: "Human kind cannot bear much reality."

Well known is the influence of radical postmodernism on a certain school of Bayesian reasoning. In a thought-provoking book, Chamont Wang discusses several misuses of statistical inference by this school. Wang notices the school's misuse of probability and points out its misunderstanding of the difference between statistical hypothesis versus scientific hypothesis (Wang 1993: 160): "A scientific hypothesis is in most cases not tested by formal statistical inference. For example, why does the scientific community accept evolution theory but rejects the religious creation theory? By setting up null and alternate hypotheses, and then conducting a Neyman-Pearson (or Bayesian) hypothesis testing?" But when a rigid mind is made up, one should not confuse it with facts and rational arguments. Therefore, it is hardly surprising that Wang's concerns were largely ignored. This is the fate of outsiders who seek the truth, and in the process they challenge the views of an organized group with vested interests. In medical studies, it is quite common that model selections that neglect substantive features of the real-world phenomenon generate misleading findings (the matter is discussed in various parts of the book). For example, after carefully evaluating the data analysis suggesting a significant correlation between cholesterol levels and the duration of formal education, Laszlo Sarkozi and his colleagues concluded that "the seeming correlation was caused by inappropriate statistical evaluation" (Sarkozi et al. 1996: 425). It is widely recognized in the medical profession that, if left unchecked, similar analyses based on misapplied statistics can lead to serious misconceptions about cardiovascular or other health risk factors.

Like Cicero, let us plea: *Quod di omen avertant*.[19] The ill-conceived postmodern perspective of health statistics can easily slip into a far too passive "anything goes" attitude that facilitates the chaotic interaction of multiple subjectivities and allows drawing substanceless conclusions concerning in situ phenomena. Perhaps, it is not by accident that this perspective flourishes in America, which many consider a country with a notoriously anti-intellectual and anti-history culture (as described in Berger 1971; Evans 1997, among others). This culture provided the fertile ground for the views of radical postmodernism to become a major industry in many aspects of American life, including research and education.

[19] May the gods avert this omen.

9.4.3 The "John Treats – John Drinks" Approach

Certain forms of statistical regression, like time-series and geostatistical Kriging techniques (Chatfield 1989; Isaaks and Srivastava 1990; Zeger et al. 2000; Dominici et al. 2003c; Ramsey et al. 2003), are based on a problematic reasoning mode. Let us focus on Kriging, which is a statistical regression technique that involves two main stages: On the basis of the dataset S of the attribute, Stage 1 calculates the dependence function D_X (covariance or variogram) that is assumed to characterize the attribute distribution. In Stage 2, the same dataset S is used together with D_X to produce attribute predictions at future points. A careful look reveals a severe methodological problem of Kriging (and other statistical regression methods, as well): If one needs the D_X function to predict the future behavior of the attribute from its past values S, and if, at the same time, one needs the same S to calculate the D_X function in the first place, then one is confronted with a serious self-reference problem. From a cultural perspective, the situation reminds one of an old proverb familiar among Greek villagers who frequent local taverns: "John treats-John drinks."[20] Self-reference issues can make the comparisons of various health regression models on the basis of technicalities (Liao et al., 2006, 2007; Sziro et al., 2007) rather useless.

This is the kind of misstep that one would expect data analysts to use their acumen to expose rather than commit. A possible resolution of the matter would be that, instead of being purely data-driven, the D_X model could be derived from substantive knowledge, such as extra-data sources and adequate understanding of the physical mechanisms (Christakos 2000). If this sort of knowledge is not available, the implementation of complicated statistics[21] can be a risky business. It is more honest to admit the infeasibility of the task than to make counterfactual claims and divert attention from the real issues. In addition to the self-reference problem, there is a false analogy of the regression methodology with deductive reasoning. In standard deductive reasoning one starts from true premises, and by using a system of logic rules, one is guaranteed that the conclusion is true. In Stage 1 of statistical regression, however, the dataset S often involves considerable uncertainty and, hence, it may not be a true premise in the deductive logic sense of the term. Accordingly, the process that leads from S to the dependence function D_X is not a rigorous system of deduction and, hence, the result is not guaranteed to be valid. In fact, one can fit more than one function D_X to the dataset S; i.e., the derivation of D_X suffers from the indetermination problem of model fitting already mentioned in a previous section. This is not the end of the story. Despite its severe methodological problems, regression modeling has become a profitable industry. The usefulness of these models is greatly exaggerated, however, which is especially

[20] This is similar to the incident mentioned in Section 6.8.2, in which the researcher who manages the research project also serves as the peer-review leader for the same project.

[21] This includes technical models involving many parameters to be estimated from the limited data.

true in environmental exposure and public health studies (e.g., Sahai and Khurshid 1995; Myers 2002; Jewell 2003; Peng et al. 2006a; Peng and Dominici 2008). The consequences of essential modeling assumptions (e.g., choice of parameter fitting or assignment of priors) are not fully appreciated. This leads to unphysical dependencies between model parameters and profound methodological inconsistencies (e.g., on the one hand, PDD emphatically requests to allow the data to speak and, on the other hand, Bayesian priors are selected before the data become available and have the chance to speak). In reality, regression models are, at best, descriptive models to be used in tightly controlled environments and for limited purposes. They are neither scientific theories nor physical or biological laws, as some would like us to believe. In which case, Wang's observation is right to the point: "Regression models cannot all be taken as seriously as scientific laws. Instead, they share similarities with the 'common sense' in our daily life: informative but error-prone . . . I would be horrified if medical researchers proposed linear statistical laws, instead of physiology and pathology, as the foundation of medical practices" (Wang 1993: 77–79).

9.4.4 Matters of Lifestyle

Betty Jackson, the legendary British fashion designer, once said that "[c]lothes should complement a man's personality, not replace it." The apparent meaning of Jackson's quote is that one's prime emphasis should be on essence rather than appearance, and that the convenience of certain means cannot substitute for substance. Which brings us to some other limitations of popular statistical models, namely, their legendary reliance upon the simplistic Gaussian and linearity hypotheses. This reliance reveals a sort of instrumentalism that is concerned not merely with the application of thought but the a priori *conditioning* of its form. In the case of the Gaussian hypothesis, most attribute values hover around the mean, and the odds of a deviation decline exponentially as one moves away from the mean. This is too strong a hypothesis as far as the distribution of the data is concerned (only the data mean and variance are essentially taken into account). In the case of the linearity hypothesis, the attribute estimators are simple (linear) combinations of data across space. In other words, the real-world is assumed to have a convenient non-Gestaltian structure (its properties are derivable by summation of its parts, consists of straight lines, and the like). Other potential limitations include: the meaningfulness of the mean squared error criterion is mostly questionable outside the Gaussian world; and widely used covariance and variogram permissibility conditions are valid only in multi-Gaussian situations, which is rarely the case in situ (Section 5.9).

According to Horace's *aurea mediocritas*, truth and goodness are supposedly found in the middle, which may explain, to some extent, the fact that the Gaussian fixation is widely observed among expert practitioners and, sometimes, turns them into what is known as "gullible Gaussians." In a widely-cited work, Donna

Spiegelman and coworkers claim that their analysis (Spiegelman et al. 2000: 51) "relies on the assumption that the error in the continuous covariates is multivariate normally distributed," which is already a mathematically convenient but often unrealistic in situ assumption. But the authors go even further to make the empirical claim that "[t]hese model assumptions are empirically verified in the validation study." This is a very strong claim: it is one thing to make a "wild" theoretical assumption (and depart on a Gaussian adventure of your own), and quite another to make an empirical claim about the assumption's verification in the real-world, especially when one knows that the in situ verification of the multivariate Gaussian assumption is almost always impossible. Along similar lines, almost every page of Chrysoula Dimitriou-Fakalou's (2007) otherwise rigorous analysis is tied up in Gaussian knots. Interestingly, this is a perspective that characterizes students of the Zen teaching: If something is boring after using it twice, use it four times, and if it is still boring, use it eight or sixteen or thirty-two, etc. times, and soon you will discover that it is not so boring anymore.

Undoubtedly, the symmetry of the Gaussian law and the linearity of the associated estimators greatly simplify analytical and numerical calculations and, therefore, allow some investigators to pretend solving more problems and publish many more, although conceptually trivial and repetitive, papers. But the main problem still remains that most of the widely used modeling tools make little sense outside the protective walls erected by these hypotheses. In this respect, the "no-nonsense practicality" doctrine is a dangerous fallacy that takes advantage of some people's tendency to prefer hypnotic stories rather than raw truths. This fallacy does not concern itself with the annoying facts about the Gaussian and linearity hypotheses. Accordingly, what really counts is that the ideas are easy to understand and can be expressed in sound bites that are catchy and pleasant to listen to. This is all that it takes to make someone successful and popular in the "easy-living" worlds of Andre Journel's indicator kriging and Billie Holiday's mellow singing.

Το πεπρωμένον φυγείν αδύνατον,[22] the ancients used to say. Although the cult of the worshipers of "quick and dirty" problem-solving techniques is not bothered by methodological inadequacies, nevertheless, these inadequacies can have serious implications in situations in which values are embedded in the way science is done and spoken. This includes in situ situations where the stakes are high, the uncertainties are considerable, and the decisions very consequential.

9.4.5 The Papier-Mâché of PDD Analysis

PDD analysis, which was *papier-mâché* from the beginning, has become a tool of limited usefulness in real-world studies, as it increasingly generates results that violate rational thinking and are disputed by basic science, and continues to confuse

[22] One cannot escape one's own fate.

mathematical simplicity with physical simplicity. As noted earlier, health statistics, in particular, needs to clarify its epistemic motivation and conceptual support. Epidemiologists favor a thinking mode based on broad statistical notions rather than case-specific concerns. This mode introduces certain epistemic standards that they do not seem willing to discuss with interdisciplinary critics. In a curious way these epidemiologists fail to realize that an interdisciplinary approach would indeed add context and depth to their own arguments. The uncritical use of numerous models supplemented with ad hoc rules and number-crunching software codes (e.g., Dominici et al. 2003a–c; Katsouyanni et al. 2009) must be reexamined. Health statistics needs to set its considerable technical expertise on the track of genuine scientific reasoning under conditions of in situ uncertainty. As a matter of fact, the "brute-force" outlook is not limited to computational data analysis. Laboratory experimentalists producing the data used in the analysis know very well how to push every button of their shining and reassuringly expensive machines, yet many of them do not have a sound understanding about the scientific theory behind the machine, which makes them liable to make mistakes. Paul Feyerabend once said, "Given a sufficient number of intelligent people with sufficient motivation, any point of view, however unreasonable, can be made to threaten any other point of view, however reasonable." It is a sign of the Decadent times that the situation has reached the critical point that attempts to present a different thinking mode or technical approach, which do not fall within the strict boundaries of the established paradigm, are immediately censored by the culture imposed by the cabal, regardless of how sound the mode and how realistic the approach may be. As a result, the research journals are full of misapplied statistics papers. It is then not surprising that as was reported by Ioannidis (2005), among others, during the last 15 years epidemiology results have been contradicted in four-fifths of the cases examined. The PDD mindset adopts the "form excludes the content" doctrine of radical postmodernism, and ignores the fact that natural law is the essential limit on the pretensions of an investigator's action for the sake of human existence and its transcendent intention. Arguably, this mindset can have quite negative effects, by essentially turning people into some sort of mechanical devices. In which case, one may even wonder whether the mindset's invented unreality has adopted the motto of the Roman satirist Petronius, *Mundus vult decipi, ergo decipiatur*,[23] on the way to the elusive Pleasantville (Postman 1985).

In sum, if there was no Eden-like harmony of intellectual interests between science and model selection at the origins of the health statistics field, there can be no noble telos either. As noted earlier, there is neither genuine dialogue nor intellectual debate in the field that involves all relevant perspectives on an equal basis, only intersecting monologues at best. This being the case, it is of upmost importance to overcome cabal's groundless objectionism, and make possible the development and preservation of a marketplace of ideas. A creative tension between abstraction and insight should find its epistemic resolution, and a

[23] That is, "the world wants to be deceived, so let it be deceived."

sound association between theoretical and insightful appraisals of reality must be established. Until this is done, the yawning gap between technical models and the reality of science-driven human exposure and space–time epidemiology will continue to widen.

9.5 Born an Original, Dying a Copy?

Let us recapitulate. One must admit that the above considerations add up to a rather extraordinary state of affairs. It is obvious that interdisciplinary problems need investigators who may believe in different paradigms. The methodology favored by an environmental engineer, e.g., can be very different than that favored by a human geographer. The situation brings to the fore most emphatically the serious challenge of integrating these different methodologies to obtain realistic solutions of important problems. Success in this endeavor requires a culture of creativity that is ultimately mixed with conceptual, technical, industrial, social, and institutional elements; and the mentalities of the various participants. Thus, the introduction of an IPS approach illustrates the importance of different perspectives in scientific investigation. One gains a much deeper insight into how a system works by approaching the problem from totally different standpoints. It is this diversity of standpoints that offers valuable insight into the essence of the mental functions by means of which investigators understand reality and solve problems.

In certain parts of the book we explored the possibility of thinking in a literary way about scientific problem-solving. Our movement between the domains of scientific and literary thinking provided us with a perspective from which to interpret as significant certain gaps in the current worldview. In the end, an IPS approach should be judged by the kind of further thinking it engenders, not by its conformity to some established paradigm. The debate is not merely whether theorizing of this sort is philosophically legitimate, but whether it is useful, whether it can bring enlightenment rather than confusion. Accordingly, in the present chapter on technology, although the emphasis was naturally on "how" (i.e., on operations and procedures to process information), once more I did not want to neglect the importance of "why" (i.e., understanding the meanings of what we know rather than merely accumulate information). This is a viewpoint that contrasts corporate science and industrialized research, where the prevailing culture is to overemphasize "how" at the cost of "why." This culture makes it easy to produce a huge number of supposedly "new" products which, unfortunately, more often than not turn out to be merely "brushed" copies of the previous ones. They add very little to the deeper understanding of the problem at hand, although they may add a lot to the bank accounts of their enterprenerial developers – operating inside and/or outside university campuses.

> The superior man understands what is right; the inferior man understands what will sell,

said Confucius. One cannot avoid thinking that there must exist a strong anti-Confucian sentiment in many campuses these days, where the strong opposition of the PCU establishment against any form of intellectual accountability[24] is justified by means of an "aspired to profit" sort of pseudo-practical research and education outlook.

Nonetheless, while living within an uninspiring culture of "copying" and "repackaging," the only hope is to appeal to inwardness and depth for a thoughtful and passionate response to the Edward Young's (1765) old question:

> Born originals, how it comes it to pass that we die copies?

Too "romantic" a goal, some readers may think. But they may find some sound justification for it, if they consider the tried alternatives and where they have led human societies today.

[24] Yet another case of "self-regulation" at work.

Chapter 10
Epilogue

There is nothing more difficult to carry out, nor more doubtful of success, nor more dangerous to handle, than to initiate a new order of things.

N. Machiavelli

10.1 Knowledge Pursued in Depth and Integrated in Breadth

As was said in the Foreword, the ideas and thoughts presented in the book rather constitute an unfinished project or, if the readers prefer, an unended quest. Yet, the notion that human agents need to be engaged in problem-solving as part of their intellectual development is an old one, going back to Aristotle who wrote about the "development of talents" (Phelps 2009). In light of the discussion in the previous chapters, one can detect a strong *knowledge synthesis* component in real-world problem-solving. Knowledge synthesis institutes a broad framework in which different sets of mental entities describing constituent phenomena in the individual disciplines are integrated to solve the composite in situ problem under conditions of multisourced uncertainty. In general, description, explanation, and prediction can be all essential elements of a composite solution. As a result of these considerations, some readers may detect some similarity between the knowledge synthesis perspective of IPS and the Quinean interpretation of problem-solution as a "matrix" or "integrated body" of multidisciplinary KBs. The Quinean "matrix" can be changed or adapted in light of new evidence or as a result of a revision in the agent's thinking style. The "matrix" allows epistemic pluralism, i.e., the adequate formulation and understanding of a specified problem may involve distinct data sources and methods of producing knowledge. An Epibraimatics premise is that the accommodation of this plurality could lead to more successful IPS.

10.1.1 Not "That" but "That by" Which We Know

Viewed as knowledge synthesis, IPS requires a group effort of theorists and technical experts from different disciplines, who share certain integration objectives.

G. Christakos, *Integrative Problem-Solving in a Time of Decadence*,
DOI 10.1007/978-90-481-9890-0_10,

The group effort relies on adequate conceptualization, rigorous formulation, substantive interpretation, and innovative implementation. As far as implementation is concerned (especially when considerable experimentation and computational means are involved), one should not be only concerned about the cost and lose the value. Naturally, the starting point of scientific inquiry is the consideration of what in fact is an important problem. Generally, ideas, experimentation, and observation can give rise to problems that are worth considering. The investigator should not underestimate the importance of finding a suitable problem to solve, which can turn out to be the most difficult part of the research process. The artistry and innovativeness of research often consists in finding important problems that can be solved, and the appropriate methods for their solution. In the Epibraimatics setting, the old knowledge is replaced over time by new knowledge that is more productive than the old one, opens up new forms of value, and can help solve previously unsolved problems. Instead of processing the limited old knowledge and trivial resources, one could master new skills to create more value from new knowledge and resources. Expert practitioners may be attracted to cherished ideas of what works, but over time, they will eventually have to move from what works to what works better.

Perceptions are not *that* which we know, but rather *that by* which we may know something about certain aspects of the real-world. Priority is given to content, context, substantive knowledge, and human values, and not merely to brain-numbing, mechanical activities. Epibraimatics modeling relates the analytical thinking (required in focused logical processing) to the synthetic thinking (required for analogies generation), and then uses them for IPS purposes. This calls for multifocus domain and divergent thinking. It promotes a synergic relation between analytically and synthetically oriented minds, as it is found between left and right brain hemispheres, by means of the corpus callosum. Then, metaphorically speaking, Epibraimatics might be perceived as a research corpus callosum, trying to bridge analytically with synthetically oriented efforts, convergent with divergent thinkers, and focused specialists with nonfocused or multifocused generalists.

Mature disciplines rely on sound theories that are built on rigorous foundations and reject naiveties (such as, e.g., “simplicity automatically brings truth”, or “let the data speak”). Formally, a scientific theory is a set of axioms (postulates) connected by logical rules and equations. What converts the theory to technological usefulness is that it is linked to Nature. An important goal of Epibraimatics is to help connecting formal theories with Nature. This connection highlights the crucial role of *stochastic reasoning* (Chapters 5–6), which is principled (not arbitrary or ad hoc) and context sensitive (a quality distinctive of intelligence). Reasoning is based on principles that are generally valid, the validity conditions are clearly described, and the two form a unity. The conclusions are meaningful only when the contextual conditions (physical, epistemic etc.) are satisfied in situ. Otherwise said, in situ reasoning is ceteris paribus: assuming that “everything else is equal.” When ceteris is not paribus, i.e. when contextuality is in question, stochastic reasoning takes this into account and is adjusted accordingly, which is characteristic of intelligent response to an open-ended variety of circumstances. In this respect, stochastic reasoning may be seen as a response to the need that standard logic be substantially enriched so that it can be used in open-ended real-world situations that elude standard logic. As was discussed in Chapters 5 and 6, in situ situations (*i*) suggest that logic and psychology mutually constrain each other in an analogous way that mathematics and physical science constrain each other, and (*ii*) stochastic reasoning establishes a fundamental symbiosis of natural laws and logic. Both *i* and *ii* take place in the uncertain environment of in situ problem-solving.

Unlike many fields that pursue knowledge in depth but in relative isolation, knowledge can be pursued in depth and integrated in breadth. To include new and critical domains, one may go beyond the existing frameworks, and potentially cause a paradigm change. One can introduce, e.g., spatiotemporal analysis from a perspective that builds on science's longstanding success as the most successful epistemic methodology that links mathematical symbols and equations with physical facts and laws. This may be necessary because "cook book" space–time data analysis lacks a coherent rationale, its assumptions (simplicity, linearity, normality etc.) are insufficient in natural sciences, and, thus, the analysis has long been under considerable criticism. To demonstrate the practical sides of the theoretical ideas, as well as the way the former are related to the latter, several quantitative models and techniques were discussed in the book, with emphasis to those that are well understood and tested in situ. Other models could have been used too, if the author was sufficiently familiar with them so that they could serve the above purpose.

10.1.2 To Find Out About Life, One Has to Model Life Itself

It has been said, and with good reason, that in order to find out about life, one has to *model* life itself. Modeling appeals to the imagination as a powerful way a natural phenomenon shows itself to us, *comme il se montre à nous*, and creates mathematical formulations, which, if properly handled, can demonstrate clearly where the limitations of our knowledge really are. Theorists wrestle with a variety of conceptual and technical issues—often, their instinct tells them to transform the former into the latter. The success of a conceptual effort usually depends on technical tools, such as numerical means and software codes for performing calculations on a computer. Yet the fruitful development and implementation of the technical tools depend on the professional skills and the creativity of the theorists who conceive them.

Uncertainty of thought and perceptual errors characterize any conceivable knowledge synthesis framework. According to Jean Baudrillard (2001), the uncertainty of the world lies in the fact that it has no equivalent anywhere, it has no meaning outside itself, and it cannot be compared to a higher reality. Similarly, Ludwig Wittgenstein believed that one would have to step outside language to comprehend everything that is expressed through language, and this includes rigorous problem-solving. Hence, there cannot be a definite verification of the world with absolute certainty *within* the world itself. The uncertainty of thought lies in the fact that it cannot be exchanged either for truth or for reality. Is it thought which tips the world over into uncertainty, or the other way around? This in itself is part of the uncertainty. In Epibraimatics, this indeterminacy leads to a variety of postulates and speculations some of which can be expressed quantitatively by means of stochastic reasoning and then used for IPS purposes. Equally important, in situ stochastic reasoning is a dynamic process that may involve alterations in mathematical language, variations in style and standards of argumentation, changes of emphasis on problem aspects, even modifications of views concerning the scope of the problem-solution. Theoretical prediction sometimes proceeds from the assumption that the situation as modeled constitutes a sort of a closed world: nothing outside that situation could intrude in time to upset predictions (Section 1.8.2.1). This assumption by itself could be the source of considerable in situ uncertainty. Multidisciplinary studies present an additional complication due to the disparity in techniques for acquiring data, developing and communicating the relevant KBs, and assessing their reliability (Klein 1996; Jakobsen et al. 2004; Lele and Norgaard 2005). Scientists often view the conceptual frameworks, assumptions, methodologies, and techniques outside their own discipline with considerable discomfort (Eigenbrode et al. 2007). It is possible for a reliability assessment method that is acceptable in one discipline to be looked upon with suspicion in another. This is, e.g., the case with the triangulation method commonly used in social sciences (Denzin 1970), but is not considered adequate in physical sciences. In a similar vein, some critics believe that peer review has a built-in bias against highly original works and results because reviewers (as do people in general) tend to be more tolerant of works and results that are consistent with their own views and more critical of those that contradict them.

But let us have another reality check. What for many scientists started as a mission to unlock the secrets of Nature or as an inquiry into the human condition has sadly turned into "just another job," in which purely financial gain is the name of the game. Sadly, the original search for truth and meaning has been reduced to a chore that allows one to frolic in the field without bothering to investigate, discover, and create. Is it a matter of character, of lacking "what it takes," something deeper? Or is it rather a matter of being victim of the circumstances, of having no other choice, of failing to appreciate one's surroundings (being isolated within the "Cavafian walls")? Whatever the case may be, it is a matter of one's introspection to discover what the real answer is.

10.1.3 La Divina Element of IPS

As we saw in Section 1.9.3, several thinkers emphasize the sense of beauty that characterizes many fundamental concepts and mathematical theories. For Godfrey Harold Hardy (1967: 85), "The mathematician's patterns, like the painter's or the poet's, must be beautiful…there is no permanent place in the world for ugly mathematics…It may be very hard to define mathematical beauty, but that is just as true of beauty of any kind – we may not know quite what we mean by a beautiful poem, but that does not prevent us from recognizing one when we read it." Another distinguished thinker has made a particularly intriguing remark (Chaitin 2005: 9): "Anyone can define a new mathematical concept … but only the beautiful and fertile ones survive. It's sort of similar to what Darwin termed sexual selection, which is the way animals (including us) choose their mates for their beauty. This is a part of Darwin's original theory of evolution…"

Mutatis mutandis, a fascinating parallel could be drawn between the desired qualities of a multidisciplinarian investigator and the qualities of an opera singer. Both must combine, in the most creative manner, a variety of skills such as innovation, creativity, versatility, and synthesis. Consider the case of the incomparable soprano Maria Callas, also known in the opera circles as *la Divina* (the Divine). The Divine Maria could play opera roles that required the synthesis of a variety of highly demanding elements: The role of Violetta in Giuseppe Verdi's *La Traviatta*[1] demanded from Callas a combination of coloratura flexibility and climatic top extension, the subtlety and legato of a true lyric soprano, and the darker, heavier, tragic accents of a dramatic persona. Opera experts were always amazed at Callas' versatility and syntheticity (Edwards 2001: 133): "A soprano who could sing with extraordinary brilliance, both dramatic opera (like *Norma*) and opera buffa (like, *Il Turco in Italia*)." Lloyd Schwartz recalls his *la Divina* experience while attending Callas' lectures at the Julliard School (New York) in the fall of 1971 (Schwartz 1995): "The most riveting lesson I heard was Callas working with a young baritone on Rigoletto's aria 'Cortigiani, vil razza dannata'…She tears into the aria with an uncanny mixture of ferocity and almost unbearable pathos…These few moments are electrifying. 'Who'd have thought the world's greatest Rigoletto would be a woman?' someone remarked after the class. She was too serious an artist ever to do anything as bizarre as record an album of baritone arias, but I bet everyone present at Juilliard that day wished she would…Why shouldn't she 'be' Rigoletto as easily as she became Carmen or Violetta?" This is the power of synthesizing personalities of large scope.

10.2 The Ionian Tradition in a Time of Decadence

In Section 1.1.2, we yearned nostalgically for the times of the Ionian thinkers. The times of unparallel creativity and genuine free thought, when "wild and crazy" ideas floated around and openly debated, to be eventually passed down to the modern world. Continuation of the Ionian tradition would depend on investigators acting as architects (in the sense of science viewed as a creative process) rather than bricklayers (in the sense of science seen as a humdrum activity). Accordingly, IPS should reconcile general and particular knowledge sources, and penetrate into the immanent content and distinct context of the in situ environment.

[1] In a memorable production by L. Luchino Visconti at *La Scala* in 1955.

10.2.1 Castoriadis' Space for Thought

Recently, scientists have claimed that although Darwinian competition has been observed on a small scale, animals diversified on a large scale by expanding into a living space, or *ecospace* (Sahney et al., 2010). Like all species, it seems that people too need their own vital space. In the Ionian tradition, Cornelius Castoriadis has suggested that influential thinkers and scholars should develop and preserve a *space for thought*,[2] which will prevent the monstrous ideas and practices of the clerkdom and its institutions to occupy the empty space (Castoriadis 1996). In a sense, this book would be seen as a modest attempt to introduce a space-time for thought, in which case the term "long essay" rather than book might be a more appropriate characterization of the tentative, the nondefinite, and the uncertain that these pages represent. The development and preservation of a space-time for thought would make interpenetration possible, discover connections even between seemingly remote topics and disciplines, seek cultivation of the mind, feed curiosity, and furnish the imagination.[3] It would install uncompromising meritocracy, allow constructive confrontation and mutual criticism, promote risk taking, and restore a sense of shame. And it would be against the bluffing, demagogy, intimidation, and prostitution of the spirit. Otherwise, one is in danger of a miserable death, the kind of death that can come from living without meaning, without intensity, without focus, purpose, or design.

In this world, and probably in many others as well, constructive *criticism* remains the only reliable guide to the truth.[4] Historical evidence amply demonstrates that scientific progress strongly relies on scientists criticizing and eventually disproving the ideas and theories generated by their predecessors. Every time period has generated information that, although at the time was considered to be of significant value, most of it was later proven to be tautological or false. In fact, every highly successful scientific field constantly compels its practitioners to think and act in this way. According to Thomas W. Martin (2007: 76), "Science eventually yields impressive answers because it compels smart people to incessantly try to disprove the ideas generated by other smart people."

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[2] *Space-time* for thought may be a more appropriate characterization in many cases.

[3] For example, integration with apparently disparate or even antithetical intellectual domains (such as philosophy, psychology, literature, history, and art) could be a source of inspiration in a state of limited conceptual advancement and creativity. In Section 9.4 we saw that health science is another field that could benefit from a space-time for thought in the form of a marketplace of ideas.

[4] One could not really agree with Edward De Bono's suggestion that, "When the world was full of speculation and fantasy, this obsession with truth served society very well...Today's society is not so full of fantasy" (De Bono, 2009: 114). On the contrary, there is plenty of evidence that the world today is full of mass media created fantasies, social simulacra, and consumerism obsessions. To quote the former British Prime Minister Tony Blair, "The truth becomes almost impossible to communicate because total frankness, relayed in the shortland of the mass media, becomes simply a weapon in the hands of opponents" (Tony Blair, *The Times*, 24 November 1987). All this makes truth an extremely valuable ingredient of human existence, and the search for truth an urgent inquiry during the Decadent phase of civilization we live in.

10.2.2 Nietzsche's Good Enemies

Friedrich Wilhelm Nietzsche famously said that a robust soul needs good enemies. This is probably true in any field of human inquiry, in which case we should do well to take up the *Nietzschenian* challenge. Unfortunately, this is not the way the clerkdom views matters of research and development. As was demonstrated in various parts of this book, the clerkdom with its ruling elites strongly opposes any kind of innovative thinking that cannot control, and is often highly suspicious of any sort of dialogue. Obviously, for the elites a good intellectual opponent is someone whose story is never heard.[5] Instead, they are perfectly satisfied to create a self-congratulatory and sterilized environment within which they can propose a set of "convenient" yet irrelevant problems with their "ready-made" answers, and then to briefly impose them on the community of the uninformed, only to be proven later inadequate when confronted with the hard realities of life. No matter, the clerkdom makes sure that the process continues with another round of "business as usual." In this climate, one is accepted by the system only to the degree that one denies oneself, and becomes alienated from oneself. Robust and pure souls feeding on constructive criticism and intellectual debate have no place in the midst of perhaps the most avaricious environment in the history of man. As far as elitist authoritarianism is concerned, intellectual influence is directly proportional to the vocal energy, the faith, and the propaganda skills of the ruling elite. This is a typical case of egocentric thinking that characterizes those individuals who do not appreciate, neither the limitations in their own viewpoints nor the rights and needs of other perspectives. As noted earlier (Section 1.11.2), these are the same individuals who have very little appreciation for tradition and achievements of the past. Yet, in many cases it was not that the thinkers of the past were ahead of their time, but that today's experts are really behind their time. If the anti-tradition mindset of radical postmodernism is taken seriously, the current generation should not feel obliged to leave something significant for future generations. Which is, in fact, the case of the so-called "Greediest Generation" (Kristof, 2005). It seems as radical postmodernism offers some sort of philosophical underpinnings for this generation.

10.2.3 A Phase of Decomposition

Early on many eminent scientists and philosophers had called people's attention to the advancing state of Decadence in modern societies, its negative effects on human inquiry and the way investigators are allowed to operate – yet their warnings went largely unnoticed. In sociopolitical terms, this indifference is not without severe consequences as implied in James Reston's statement: "all politics are based on the

[5] Again, see section on "The Shadow Epistemology," Section 1.4.

indifference of the majority." In his late years, Albert Einstein expressed his deep disappointment of the *status quo* by commenting that,

> In the present circumstances the only profession I would choose would be one where earning a living had nothing to do with the search for knowledge.

Conveniently misinterpreting Einstein's quote, the power holders dominated the PCU campuses with combinations of corporatism and radical deconstructionism that promote meaninglessness, dislike of tradition, and even nihilism (Sections1.3–1.5). This has turned generations of unsuspected students to instinctual animals with a huge appetite for consumption but with empty souls, rather than educated citizens and sensitive human beings. The uncompromising utilitarianism of corporate science continuously encourages an increasing number of thinkers not to seek truth and meaning in their professional lives, but more power and financial gain. This is a world where people are cut from their roots and alienated from the system of values, a world that debases life to an ephemeral appearance of consumption, a world in which means and ends are inverted, a world that prospers at a high cost for genuine human inquiry and society at large. Perhaps, this is not merely a phase of *crisis* in the sense of a moment of decision characterized by opposing elements that engage each other. Instead, the ruling elites have instigated what Cornelius Castoriadis has called *a phase of decomposition* characterized by the elimination of opposing programs and intellectual conflict, and discouraging people to participate in real debates. The decomposition phase leads to the disappearance of significations, and the almost complete evanescence of human values. Under the circumstances, Noam Chomsky was presumably right when he suggested that people ought to engage in "a course of intellectual self-defence," to prevent the power holders manipulate public opinion in order to promote their self-serving agendas. For Epibraimatics, investigators can be effective problem-solvers only by cultivating constantly an open sensory awareness that covers all thinking and acting that take place in their surroundings (Section 1.3.1).

10.3 The "Socrates or Galileo" Dilemma

Without any doubt, Socrates and Galileo are two key personalities in the history of human thought. Although they have many things in common when it comes to matters of pure genius and great vision, the two men demonstrated distinct behaviors in the most defining moments of their lives. Socrates is considered one of the great saints of philosophy, and one of its earliest tragic heroes and martyrs. He refused to compromise his principles and values. Eventually, his insistence on truth and decency led to his execution by the political clerkdom of his time.[6] Galileo, on the other hand, apparently went against his own beliefs, and agreed

[6] Socrates last day on earth is vividly described in Plato's dialogue *Phaedo*.

with the demands of the Inquisition in order to save his life.[7] Plato's and Xenophon's accounts of Socrate's trial make it clear that Socrates would have been released if he had followed Galileo's approach and had capitulated.

Which approach was the most appropriate? That of Socrates, who sacrificed his own life for noble principles and values, thus offering a unique example of human dignity? Or that of Galileo, who pretended to abandon his values and beliefs in order to save his life and continue working for the progress of science? In the view of many scholars, the "Socrates or Galileo" dilemma remains a major open question in the field of moral philosophy and ethics studies. In any case, what both examples teach us is that scientific inquiry may demand certain sacrifices, large or small, from its "servants."

Throughout history, the wise men have used many different ways to deal with the situation. As we saw above, Socrates decided to defy the clerkdom of the corrupted Athenian politics. Plato used the now famous *Platonic irony* (i.e., the feigning of ignorance in order to get someone to make a fool of oneself). Galileo pretended to capitulate to Inquisition's ignorance. Shakespeare also used a kind of Platonic irony to protect himself from public persecution and censorship. Unfortunately, this does not seem to have been the case of the Chinese intellectuals of the period 1956–1957, many of whom did not manage to protect themselves during the *Hundred Flowers Campaign*. This was a period when the Chinese communist party encouraged the consideration of a variety of views and solutions to ongoing policy problems. Famous is chairman Mao Tse-Tung's message: "Let a hundred flowers bloom, let a hundred schools of thought contend." Inspired by what seemed to be a visionary message, and trusting the party's good intentions, several intellectuals openly criticized the Communist party. This situation was initially tolerated and even encouraged by the party, but the party soon reversed its policy, thus leading to the persecution of many citizens.

Integrative problem-solvers who operate within an environment created by the decadent elites, on occasion are confronted with the "Socrates or Galileo" dilemma that cannot be always resolved in a straightforward manner. In a sense, the dilemma may be related to the so-called "wise man's paradox," which states that one needs to find a way to move safely and productively in an environment characterized by ignorance, mediocrity, corruption, and danger.

10.4 Like Travelers of the Legendary Khorasan Highway

The search for understanding is a meditation on the human condition. As such, it is a huge labor of analysis, description, and evocation that must be conducted against a background of professional disillusion concerning the idea and objectives of human inquiry. In this respect, Epibraimatics' aim, at a minimum, is to lay bare

[7] It has been reported that after admitting that the Earth did not move, the great man said under his breath, "But it does move."

these questions that have been hidden by the mainstream answers. Under the circumstances, the *Highway of Knowledge* is at least as long and uncertain as the legendary *Khorasan Highway* of ancient Asia that led from the limits of the East to the West, from Babylon to Bactria, and joined the rising to the setting of the sun. The great Khorasan Highway climbed through the Zagros Mountains, winding along riverbeds or threading between jagged pinnacles and ravines, running through a series of wide and fertile valleys. Over the millennia, the Khorasan Highway had been followed by any number of travelers: nomads, caravans, and the armies of conquering kings. Only a beneficent deity, it was assumed, could ever have fashioned such a wonder. Who, and when, no one really knew for sure, but it was certainly very ancient—perhaps, some said, as old as time itself.

To understand truth and face reality, the modern travelers of the "Highway of Knowledge" know very well that the adequate contextualization and rigorous assessment of all sorts of uncertainty are key elements of the human journey. Consider in situ predictions – they almost always involve an element of defeasibility. If a model predicts what would (under certain circumstances or assumptions) happen, one must presume that there are no unknown parameters that might interfere with those parameters and conditions that are known. In the reality of the Khorasan Highway, however, any prediction can be upset by such unanticipated interventions. In a literary fashion, while walking on the top of the mountains, the travelers could even conceive human uncertainty as a sea of fog that enfolds earthly reality below them, and then search for gaps in the fog through which they can communicate with reality and understand it. The travelers need to leave institutional arrangements behind them, and focus only on activities that will allow them to be themselves, and be able to regard opinions with a neutral and objective footing. On occasion, the travelers should be willing to forsake any of their opinions, if new and contradictory evidence surfaces, because their center is not rooted in any particular opinion. In this way, they deal with the ability to become and to remain human beings, even when confronted by nearly impossible forms of co-existence. Equally important, the co-existence and the kinds of problems it implies will certainly require that the travelers engage themselves in integrative thinking across disciplinary lines and build the inquiry skills foundational to life-long learning, self-improvement, and problem-solving.

This is not an easy affair. It is much easier for one to be a clerkdom protégé, even if this implies that one has to become something that one actually is not. Indeed, many people are most comfortable when are snug inside a group who espouse the same opinions and protect common interests, even if this means that they have to cling stubbornly to mediocrity. After all, keeping up appearances, developing one's own simulacrum, and engaging in celebrity culture are often what really counts in a media-controlled world. Several centuries ago, the cynical Niccolo Machiavelli had made an insightful observation that fits well our corporate culture:

> Everybody sees what you appear to be, few understand what you really are, and those few will not dare to oppose themselves to the many.

There is no exception. The PCU professoriat travels its own Khorasan Highway nowadays, although the highway seems to get longer and the travel conditions to worsen. The professoriat is "traveling the globe to establish the kind of international reputation that's now necessary to thrive… routinely spend much more time away from their campuses now than they ever did in the past…They travel to present their work at far-flung seminars where they might meet luminaries who could give their work a nod come tenure time" (Kiewel 2010). And, like all other groups of travelers through the ages, the traveling professoriat hopes that all this is worth the effort and risk.

Let us not forget that the travelers of the Khorasan Highway who made the final passage through the rough mountains with dangerous paths and jagged ravines were eventually rewarded by the magnificent image that lied in front of them: "A palace set within seven gleaming walls, each one painted a different color, and on the two innermost circuits, bolted to their battlements, plates of silver and gold. This was Ecbatana, stronghold of the kings of Media, and already, barely a century after its foundation, the crossroads of the world" (Holland 2007: 7). Viewed as a traveler's companion, this book is guided by the twofold narrative of the Enlightenment: *meliorist* (problem solutions can improve by effort, in piecemeal and incremental manner, without any assurance that the solutions will one day become perfect) and *fallibist* (progress in IPS is not inevitable or irreversible; it can take a long time to obtain a reasonable solution, progress can fail or be subject to setbacks).

10.5 Waiting For The Master of Ceremonies

A few centuries ago, Adam Smith famously said that, "The principal architects of state policy make sure that their own interests are most particularly attended to, however grievous the consequences for others, including the people of England." Smith's observation is valid diachronically and at a worldwide scale. Depending on the domain of interest (society, science, education, or culture), the ruling cabals implement a variety of methods although the goal remains basically the same one, as revealed by Smith. In times of prolonged Decadence, the system makes an Adornonian *minima moralia* distinction between these individuals who have to play cabals' game because they cannot otherwise survive, and those who can survive otherwise but are kept out of the system because they do not want to play the game (Adorno 2005).

Those who decide to play cabal's game need to indulge in the study of *shadow epistemology* and familiarize themselves with the communication metarules that ritualize the control of key knowledge, ex dolo politeness, courtiership, and the like (see Section 1.4). Francis Crick was probably aware of the situation when he observed that, "Politeness is the poison of all good collaboration in science." The ruling elites invented shadow epistemology to explain the demands of their own convenience. Its metarules (Section 1.4) often discourage theorists from criticizing the experimental projects of corporate science even if it is obvious that their findings are unreliable and uncertain in ways often unknown to those who obtained them. *Inter alia*, it is not uncommon that results are obtained in a laboratory using instruments based on the phenomenon they are supposed to investigate, in which case one essentially claims to have demonstrated the validity of a relationship using an instrument that has been built to operate according to the same relationship. Alan F. Chalmers (1999: 38–39), e.g., describes an experiment in which investigators were studying "electric current-magnetic field" relationships using an ammeter that had been constructed based on the magnetic phenomenon they were supposed to investigate in the first place. The restrictions on the dissemination of knowledge imposed by the cabals, and the relation between knowledge, power, and status give them a key role in determining scientific prestige and social stratification. These matters are indispensable elements of the clerkdom's *modus operandi*, where a scientific debate is in its essence a struggle of interests and forces, not of arguments. Accordingly, truth telling is a matter of exercise of power. While supposedly seeking to maintain civility in human affairs, the real purpose of the phony calculated politeness culture is to make it socially unacceptable[8] and even punishable for inquisitive minds to raise "impolite" questions that could challenge the system's policies and version of the "truth" and, as a result, potentially put at risk the system's domination.

The increasing outrage against the influence corporations assert over scientific research and education has been described by many authors (e.g., Brodeur, 1985; and Levenstein, 1991; Pearce 1996, 2007; Fagin and Lavelle, 1999), so that there is no need to repeat their disconcerting findings here. Instead, brief presentations are given in various parts of the book and, when necessary, the readers are referred to the relevant publications. Nobleman and noblewomen of thought are the prime targets of systematic psychological smearing and harassment of the sorts that in some cases would make the practices of the *Z Directorate*[9] look like school bullying. Those trapped in such an environment are often obliged to accept with a fake smile all sorts of deception, ranging from the innocent "white lies" all the way to the most vicious libels. In this sense, the culture of calculated politeness is more toxic to the human soul and existence than blatant rudeness (which may be, in fact, necessary when dealing with the clerkdom and its cronies). Instead of noble thinking, sharp insight, and constructive criticism, shadow epistemology encourages courtiership, i.e. ingratiating oneself with anybody and everybody who could do one a service or grant one a privilege. The courtiership culture is a public relationships affair—flattering established groups, subscribing to fashionable views, and making influential friends. On the other hand, outsiders should not complain even when they are robbed of their souls, careers and properties. One is inclined to believe that inquisitive thinkers and scientific investigators who achieve their goals by means of their high-level professional and human qualifications are becoming a small minority working against increasingly heavy odds.

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[8] "Socially inappropriate," "uncivil behavior" etc. are some of the phrases used for the same purpose.

[9] The Directorate Z of the old Soviet Union's KGB (Komitet Gosudarstvennoĭ Bezopasnosti), i.e., Intelligence and Internal Security Agency, was responsible for censorship and internal security against artistic, political, scientific, and religious dissensions.

Depending on the convergence of PCU vested interests, the campus simulacrum has been built on the basis of a bizarre combination of ruthless corporatism and radical postmodernism (characterized by dubious policies, boundless opportunism, professional nihilism, and political correctness). In many places, the PCU campus atmosphere somehow resembles the debauched scene of the pre-war Berlin nightclub in which nothing was left but for the *Master of Ceremonies* to tear the bandages from the patrons' eyes, thus revealing the ugliness of their lives. It may not be long before the PCU simulacra follow the fate of their Wall Street market counterparts. In the meantime, the social decay caused by these simulacra directly affect the souls and minds of people, which makes any future recovery effort a much more difficult yet urgent matter. Future generations will probably suffer for the sins of the present one that dissipated the wealth accumulated by previous generations in endless consumerism, foolish pomp, and the frenetic chase of material pleasures. There is no concern to pass to future generations stronger values, a more refined view of meaning and purpose in life, and improved knowledge of the laws of Nature. In this sense, the present generation is the robber of generations of unborn millions, and nobody can plead ignorance in this respect. It is a sign of the times that the flourishing commercial system of the glorious old era that made possible for inspired travelers from different parts of Asia to follow the highly prosperous "Silk road" bringing quality goods to the West has been replaced by a modern system that has caused millions of impoverished human beings from the same parts of Asia to walk the "Hunger road" carrying their desperation to western societies. It is stunning to compare the treacherous "Hunger road" with the slippery "Consumerism road" of western societies (and not only) that leads from the boredom of producing and consuming things to the loss of meaning, authentic well-being, and purpose. It will not be by accident if the ending of Decadence and the emergence of a New Enlightenment coincides with the passing away of the cursed era that has seriously damaged intellectual achievements and real values that had taken humanity many centuries to establish. Some people seem to anticipate that after it has sucked the blood out of many people's lives, the vampire system with its money-metric delusions will eventually destroy itself very much like the voracious mythical bird that ate itself.

10.6 A Matter of "*Eύ Zήν*" Rather than Merely "*Zήν*"

In the beginning of our long promenade through the territories of knowledge we were reminded of the ancient road to Damascus where Paul of Tarsus saw the bright light of truth and knowledge that forever changed his life (Section 1.6). That was Damascus in the first century AD. Fig. 10.1, on the other hand, is Damascus in the twenty first century AD. The photo sends a message more powerful than hundred books together could send (including the present one). One cannot but deeply admire the little girl's search for the bright light of knowledge that could change her life. In the city sidewalks she has given meaning and purpose to life that the "train-and-entertain"

Fig. 10.1 An unidentified seven year old girl busy studying while sitting on a sidewalk in Damascus as she was selling candies (2006; photo by Wasim Kheir Beik)

model (Section 1.5.5), with its tacit acceptance of inhumanity and delight in emptiness, will never be able to evoke and inspire.

The union of self-serving agenda and political correctness often characterizes those who are too cowardly to fight and too fat to run. The book suggests a different path. It raises emphatically a call for action against Decadence and its effects on IPS in the real-world. In an effort to convey its message to the readers, the book made an extensive use of scientific, mathematical, philosophical, psychological, literary, and idiomatic allusions in an IPS framework. Let me conclude the journey by acknowledging that the discussion in the book revealed a relish for intellectual debate, regarding it as the antidote to that conformism so widely present in the world of academics, experts, specialists, and professional politicians of all kinds. I must also admit that, in my effort to make a point, in some parts of the book I may have risked the crudity of plain statement, and may have even employed some exaggeration. But there is an excuse for this: A real obstacle to progress is that not enough people are sufficiently in despair with the power holders. Instead, they seem to be psychologically attached to the "perpetual optimism" illusion masterfully promoted by the clerkdom during a time of Decadence. Which is why these people use so frequently the term "optimism" (which expresses a psychological choice, not necessarily rational) rather than the term "hopeful" (which expresses logical argumentation). As noted earlier, the optimism of the consumptionism model has been attributed, at least in part, to veiled opportunism and a manic lack of insight. Which is why, I chose to be hopeful about the fate of this book, although by no means waiting for the world to beat a path to my door.

As noted earlier, different disciplines study different elements of language, humanity, and Nature. Nevertheless, all these disciplines are interlinked and interdependent, which means that in situ IPS needs their close cooperation and trust. Hence, problem-solvers should leave an intellectual door ajar to admit the visit of the unforeseen; maintain a space-time for thought, in which their analytical and observational skills can be integrated with mental finesse, fuse form and content, and seek the big picture; and follow Nietzsche's old advice to avoid associating their intellectual journey with the ideologies of the ruling elites of the time, because this will most certainly blank out any aspects of individuality and uniqueness they possess. After all, one's goal is not merely the "*ζήν*" (living organized in purely utilitarian terms) but the "*εύ ζήν*" (living characterized by self-cultivation and introspection), which could offer a chance to break out of a regulated and conventionalised world. It is astonishing, indeed, what huge difference in one's life this little "εΰ" makes. From a certain perspective, people set the standards by which they would have others judge them.[10] Perhaps, to understand a book of this kind one has to go first through the kind of thought process that the author went through in writing it. In a complementary manner, one would be also reader of one's own self, the book serving as a magnifying glass. This requires an act of self-discovery on the part of the reader that expands one's consciousness. After all, the main reason for writing a book is to experience, as much as a one's own abilities make it possible, the "εύ *ζήν*" process, regardless of its potential consequences. Because, as Odysseus Elytis wrote:

> And let them say we walk with our heads in the clouds.
> Those who have never felt, my friend,
> With what iron, what stones, what blood, what fire,
> We build, dream, and sing.

Surely, some books and activities invite the usual "criticism," slandering may be closer the mark in some cases, by all sorts of well-off members of the clerkdom and the ruling cabals, small or large. Again and again, the same deceptive clichés and dissimulations have been used by them, in a calculated effort to discredit or distract attention from works not serviceable to the clerkdom' designs. Really, only those who have willingly surrendered their souls to the slavery of the establishment take seriously such clichés and dissimulations. Not to mention that the clerkdom's intentionally deceiving language and ridiculous rituals strongly remind one what Vaclav Havel called (Havel 1990), "a world of appearances, a mere ritual, a formal language deprived of semantic contact with reality and transformed into a system of ritual signs that replace reality with pseudo-reality."

On the other hand, what probably frightens many people is this: If everything of human concern ends up just two meters under the ground, the clerkdom's amoralistic worldview would be probably considered the ultimate philosophical system.

[10] Which is what Protagoras probably meant when he declared that, "Man is the measure of all things" (Fuller, 2006: 10).

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"It is not once nor twice but times without number that the same ideas make their appearance in the world."

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