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Takao Terano Toyoaki Nishida
Akira Namatame Syusaku Tsumoto
Yukio Ohsawa Takashi Washio (Eds.)

New Frontiers in Artificial Intelligence

Joint JSAI 2001 Workshop Post-Proceedings



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Series Editors

Jaime G. Carbonell, Carnegie Mellon University, Pittsburgh, PA, USA
Jörg Siekmann, University of Saarland, Saarbrücken, Germany

Volume Editors

Takao Terano
Yukio Ohsawa
The University of Tsukuba, Graduate School of Business Science
E-mail: {terano/osawa}@gssm.otsuka.tsukuba.ac.jp

Toyoaki Nishida
The University of Tokyo, School of Engineering
E-mail: nishida@kc.t.u-tokyo.ac.jp

Akira Namatame
National Defense Academy, Dept. of Computer Science
E-mail: nama@nda.ac.jp

Syusaku Tsumoto
Shimane Medical University, School of Medicines
E-mail: tsumoto@shimane-med.ac.jp

Takashi Washio
Osaka University, The Institute of Scientific and Industrial Research
E-mail: washio@ar.sanken.osaka-u.ac.jp

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Preface

The Japanese Society for Artificial Intelligence (JSAI) was established in July 1986. Since then, we have held conferences every year. Although JSAI is the second largest community in the world focusing on the area of Artificial Intelligence and we have over 3,000 members, the importance of the research presented and discussions held at the annual conferences has not been fully recognized in the Artificial Intelligence communities elsewhere in the world, partly because most presentations are made in the Japanese language. Therefore, the program committee of the Fifteenth Annual Conference of JSAI decided to open the door to the world and hold international workshops during the conference on May 20th and 25th, 2001 in Matsue City, Japan.

The workshop proposals were gathered from the members of JSAI. We accepted the following up-to-date and exciting topics: 1) Social Intelligence Design chaired by Prof. Toyoaki Nishida, University of Tokyo, 2) Agent-Based Approaches in Economic and Social Complex Systems chaired by Prof. Akira Namatame, National Academy of Defense, 3) Rough Set Theory and Granular Computing chaired by Prof. Shusaku Tsumoto, Shimane Medical University, 4) Chance Discovery chaired by Prof. Yukio Osawa, and 5) Challenge in Knowledge Discovery and Data Mining chaired by Prof. Takashi Washio, Osaka University. These workshops were highly welcome and successful. A total of 116 people in Japan and 30 researchers from abroad participated in them.

This volume of the proceedings contains selected papers presented at the workshops. The contents of the volume are divided into five parts, each of which corresponds to the topics of the workshops. Each paper was strictly reviewed by the committee members of the workshops. They also cover recent divergent areas of artificial intelligence. We believe that the volume is highly useful for both researchers and practitioners who have interests in recent advances in artificial intelligence.

October 2001

Takao Terano

JSAI Workshops as International Trends

Looking at the current economic, political, and ecological situations, we become aware of the dynamic environment surrounding all human activities. Hand in hand, the expansion of the World Wide Web is activating the whole globe as an information system including humans, computers, and networks.

The workshop topics associated with JSAI 2001 were designed to hit such world wide trends. Social Information Designs are needed to aid the mutual progress of human society and various kinds of information flows. The Agent-Based Simulations consider social behavior from the aspect of economics, with the up-to-date viewpoint of complexity. Rough Set Theories may achieve a breakthrough with regard to dealing with uncertain real world events on the basis of established theories. Chance Discovery is a new direction proposed by Japanese researches, for helping people and agents be aware of novel information, significant for their own decisions in dynamic environments. KDD-Challengers are responding to requirements for new knowledge to be obtained from new data in new social situations.

I am sure the selected papers from these first international workshops associated with JSAI will win the attention of people from several different areas of research, not only artificial intelligence but also social sciences and other areas looking into the future of human life. A piece of good news for those readers is that JSAI is becoming increasingly international, after many years as a semi-domestic Japanese AI community. With the foundation of five workshop themes this year, the new generation of AI researchers is finding new problems and new solutions in the creative atmosphere. On behalf of all the workshop organizers, I wish to draw readers' attention to forthcoming international JSAI events.

Before beginning the contents, let us express our gratitude to the great support given by the co-editors who organized each workshop, all authors and audiences, JSAI committee members, Shimane prefecture and Matsue city, and Jun'ichiro Mori of the University of Tokyo whose operations greatly aided this publication.

October 2001

Yukio Ohsawa

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1. Social Intelligence Design – An Overview

Toyoaki Nishida

Department of Information and Communication Engineering
Graduate School of Information Science and Technology
The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
nishida@kc.t.u-tokyo.ac.jp

1.1 Introduction

The advent of the Internet and information technology has brought about significant progress in augmenting the way people can interact with each other in a totally new fashion that was not possible in the past. Examples of new technologies include conversational agents that mediate people in getting to know and communicate with each other, a collaborative virtual environment for large-scale discussions, personalized information tools for helping cross-cultural communication, interactive community media for augmenting community awareness and memory, to name just a few.

Sometimes new technologies induce the emergence of a new language and lifestyle. For example, interactive multimedia websites are a new medium and probably even a new language, with interesting new conventions, and increasing adaptation to the support of communities. Japanese teenagers have developed a new language for use originally with beepers and now with mobile phones. These are both new mainstream real world developments that should be studied further, and could probably give some valuable insights.

The theme of Social Intelligence Design is really an angle on the support of groups in pursuit of their goals, whether that is medical knowledge, stock trading, or teenage gossip. Social Intelligence Design gives some new life to Agent Technology and Artificial Intelligence research in general in that humans are integral part of a big picture by shifting the focus, from building artifacts with the problem solving or learning ability, to designing a framework of interaction that leads to creation of new knowledge and relationship among participants. Promising application domains of Social Intelligence Design include collaborative environment, e-learning, knowledge management, community support systems, symbiosis of humans and artifacts, crisis management, and digital democracy.

In what follows, I will overview major issues involved in Social Intelligence Design and attempt at structure them in a coherent story.¹

¹ The following description is indebted to the discussions at JSAI-Synsophy International Workshop on Social Intelligence Design, Matsue, Japan, May 21-22, 2001.

1.2 Horizon of Social Intelligence Design

Social Intelligence Design is a discipline aimed at understanding and supporting social intelligence. Conventionally, social intelligence has been discussed in the context of an individual's ability, e.g., an ability to be able to manage relationship with other agents and act wisely in a situation governed by an implicit or explicit set of shared rules, based on an ability of monitoring and understanding of other agents' mental state. It is distinguished from other kinds of intelligence such as problem solving intelligence (ability to solve logically complex problems) or emotional intelligence (ability to monitor one's own and others' emotions and to use the information to guide one's thinking and actions).

Alternatively, social intelligence might be attributed to a collection of agents and defined as an ability to manage complexity and learn from experiences as a function of the design of social structure. This view emphasizes the role of social rules or culture that constrain the way individual agents behave. We might attribute a good social behavior to a good social structure and consider that a good social structure affords the members of the community to learn from each other.

In Social Intelligence Design, we intermingle these two views and look at both sides of social intelligence. The "social intelligence as an individual's ability" view is related to designing a personal assistance or socially intelligent agents. On the other hand, the "social intelligence as a collective ability" view is concerned with the design of group/community support systems.

Social Intelligence Design is truly an interdisciplinary field. The engineering aspects of Social Intelligence Design involve design and implementation of systems that range from group/team oriented collaboration support systems that facilitate intimate, goal-oriented interaction among participants, to community support systems that support large-scale online-discussion. The scientific aspects of Social Intelligence Design are concerned with cognitive and social psychological understanding of social intelligence. In addition, economy, sociology, ethics and many other disciplines constitute the foundation of Social Intelligence Design. Engineering approaches should be tightly coupled with sociological and cognitive approaches to predict and assess the effects of social intelligence augmentation systems on the human society. On the other hand, novel insights may be obtained in sociology, cognitive psychology and other humanity studies by investigating a new virtualized society where humans and artifacts cohabit.

Typical applications of Social Intelligence Design are group/team support systems and community support systems. Community support systems provide rather long-range, bottom-up communicative functions in the background of daily life. Major issues are: (i) exchanging awareness with other members, (ii) exploring human and knowledge networks, (iii) building community knowledge, (iv) organizing public events, (v) forming a group/team for collaborative work, (vi) helping negotiate with others, and (vii) supporting public discussions and decision making about the community. In contrast, group/team support systems focus on facilitating more intimate collaboration among members. Thus, group/team support systems emphasize more task-driven, short-range collaboration, although awareness is equally emphasized.

Table 1. Horizon of Social Intelligence Design

-
- methods of establishing the social context
 - awareness of connectedness [16]
 - circulating personal views [6]
 - sharing stories [20]
 - embodied conversational agents and social intelligence
 - knowledge exchange by virtualized egos [8]
 - conversational agents for mediating discussions [18]
 - a virtual world habited by autonomous conversational agents [15]
 - social learning with a conversational interface [9]
 - conversations as a principle of designing complex systems [7]
 - artifacts capable of making embodied communication [19]
 - collaboration design
 - integrating the physical space, electronic content, and interaction [3]
 - using multi agent system to help people in a complex situation [2]
 - evaluating communication infrastructure in terms of collaboration support [11]
 - public discourse
 - visualization [14]
 - social awareness support [14]
 - integrating Surveys, Delphis and Mediation for democratic participation [10]
 - theoretical aspects of social intelligence design
 - understanding group dynamics of knowledge creation [1]
 - understanding consensus formation process [13]
 - theory of common ground in language use [17]
 - attachment-based learning for social learning [12]
 - evaluation of social intelligence
 - network analysis [5]
 - hybrid method [4]
-

The scope of Social Intelligence Design as a discipline of understanding and supporting social intelligence is summarized in Table 1. On the one hand, Social Intelligence Design is concerned with design and implementation of novel communication means for mediating interaction among people and agents. The scope ranges from preliminary and preparatory interactions among people such as knowing who's who, to more intimate interaction such as collaboration. Supporting a group formation, collaboration, negotiation, public discussion or social learning is considered to be an important application of Social Intelligence Design. Theoretical aspects, as well as pragmatic aspects, should be taken into account in designing, deploying, and evaluating social intelligence support tools. In the rest of this section, I will overview major issues in Social Intelligence Design.

1.2.1 Methods of Establishing the Social Context

The common ground need to be established in order for social intelligence to emerge from interaction among agents, especially when the agents are located in a geographically distant places. A sub field of Social Intelligence Design is devoted to the design of a new communication medium for a community or a group. The role of communication medium is not only to meet primary communication goals, i.e., transmitting an intended content, but also providing contextual information that may help interpret the content. It is often the case in our daily life that conversation is not for achieving higher-level goals such as information seeking, but merely for social interaction such as maintaining human relation. Such social interaction is important to constitute a social context such as trust.

One approach is to support social awareness. Ohguro proposes to support the awareness of connectedness with FaintPop, which is a nonverbal communication device similar to a photo frame [16] in which small photos or icons of the user's colleagues are displayed. FaintPop allows the user to communicate her/his feeling towards her/his colleagues by using the three types of touching (a tap to communicate a neutral feeling, a pet a positive feeling, and a hit a negative feeling).

In contrast, one may design a verbal communication medium to exchange more explicit information. The Public Opinion Channel (POC) [6] is a community-wide interactive broadcasting system. A POC continuously collects messages from people in a community and broadcasts summarized messages to the community. POC is not intended to be a system that broadcasts public opinions per se. Instead, it is intended to broadcast people's personal views arising in a daily life, e.g., questions, stories, findings, jokes, or proposals. These messages are considered to form a social context that can serve as a basis of public opinion formation.

IBM's WorldJam [20] is a large-scale corporate-wide discussion wherein all IBMers worldwide are invited to participate in. The system provides an interface that allows each participant to quickly see the concurrent view of who else is present and which topics are being discussed. Thomas suggests that keys to innovate are with designing interface that can (i) facilitate engagement, (ii) allow the user to bring to bear necessary skills, talents, and knowledge sources on the problem, and (iii) use appropriate representations of the situation. He also points out the importance of stories and organizational issues. Stories allow the user to associate the content with previous experience. The organizational structure consisting of such people as moderators and facilitators plays a critical role in the WorldJam large-scale discussion experiment.

1.2.2 Embodied Conversational Agents and Social Intelligence

Conversation plays varieties of roles in human societies. It not only allows people to exchange information in a casual fashion, but it also helps them create new ideas or manage human relations.

Embodied conversational agents can be used to augment social intelligence by mediating conversations among people. Kubota and Nishida use a talking-virtualized-egos metaphor in EgoChat [8] to enable a sophisticated asynchronous

communication among community members. A virtualized ego mainly plays two functions. First, it stores and maintains the user's personal memory. Second, it presents the content of the personal memory on behalf of the user at appropriate situations. A virtualized ego serves as a portal to the memory and knowledge of a person. It accumulates information about a person and allows her/his colleague to access the information by following an ordinary spoken-language conversation mode, not by going up and down a complex directory in search for possibly existent information, or by deliberately issuing commands for information retrieval. In addition, virtualized ego may embody tacit and non-verbal knowledge about the person so that more subtle messages such as attitude can be communicated. Takahashi and Takeda use avatar-like conversational agents in a similar vein [18]. The user can use her/his agent to give comments on a web page. It extends collaborative annotation in such a way that the users can encode subtle feelings in emotional expressions of agents.

In a more sophisticated applications, building a rich conversational environment becomes more important. Nijholt argues building a theater environment that provides the user with an information-rich virtual environment mimicking real theater buildings in a real town where autonomous agents with varying abilities cohabit [15]. The theater environment allows the user to be immersed in the virtual world and follow continuous verbal/nonverbal interactions with agents. He is introducing the internal model of autonomous agents in terms of beliefs, desires, plans, and emotions, to realize a theater community.

Conversational characters can also be employed in the learning environment. Kaktus is a computer game environment that is designed so that the teenager student can interact with semi-autonomous emotionally intelligent characters to learn socio-emotional relations [9]. The notions of conversations and social intelligence are useful in designing complex systems. Goguen suggests experimenting with an appropriate blend of interaction metaphors in building interfaces to theorem provers [7].

In the real world applications, more issues such as embodiment should be taken into account. Terada and Nishida discuss designing an artifact capable of making embodied communication with people and other agents [19]. An interesting issue is how one can allow agents with different embodiment to communicate with each other.

1.2.3 Collaboration Design

Collaboration design is concerned with goal-oriented, more intimate interaction. In addition to basic communication facilities, the nature of interaction in collaborative activities should be studied in detail.

Principles and guidelines are necessary to design collaboration support systems. Fruchter points out that it is beneficial to consider in terms of three perspectives, namely, physical spaces ("bricks"), electronic content ("bits") and the way people communicate with each other ("interaction") [3]. She suggests that by properly understanding the relationship between bricks, bits, and interaction, one can design spaces that better afford communicative events, develop collaboration tech-

nologies that can best support the joint activities of people, and engage people in rich communicative experiences that enable them to immerse in their activity.

Sometimes, e.g., in the case of emergence, it is desirable for a collection of people to be guided by socially intelligent agents in order to avoid a panic. Cardon proposes to employ a hierarchy of multiple agents consisting of what he calls aspectual agents and morphological agents [2]. In order to cope with the outcome of unexpected structure, he emphasizes the importance of a mechanism that allows meaning to be dynamically generated in communication.

The communication infrastructure may influence the way of distant collaboration. For example, replacing HDTV (High Definition TV) by normal video may make a qualitative difference in collaboration style. Mark and DeFlorio suggest that since the HDTV provides high-resolution image, people do not use exaggerated gestures or movements to convey expression through the HDTV image, which was reported to happen in normal videoconferences [11].

1.2.4 Public Discourse

A group/community/society as a whole has to make decision from time to time. Effective use of information and communication technologies are sought to support public discussion and decision-making. Nakata argues that critical issues in designing a discussion support system are (i) ease of information access and proactive information gathering, (ii) user-friendly access to a scientific analysis toolkit, (iii) evaluation of deliberative states, and (iv) guiding discussion through discussion and consensus generation models [14]. He also points out the importance of supporting individuals so that they can collect and exchange information and opinions.

Information and communication technology might bring a novel participation and discussion scheme into democracy. Luehrs et al [10] attempt at combining survey techniques, delphi approaches, and mediation method into a new methodology for on-line democratic participation and interactive conflict resolution. Their system integrates mass opinion polls, cyclical decision-making process exploiting expert knowledge, and an open process of participative conflict resolution, adapted from Surveys, Delphi, and Mediation, respectively.

1.2.5 Theoretical Aspects of Social Intelligence Design

Theories play several roles in Social Intelligence Design. In addition to their principal role of providing a framework for understanding phenomenon, theories tell us more direct implications such as guidelines of designing community/group support systems or an inventory of known pitfalls that should be taken into account in system design.

In social psychology, notorious examples such as groupthink (i.e., a phenomenon that collective creativity does not exceed individual creativity) or the hostility to out-groups (i.e., a group member has hostility to out-groups easily) are known to hinder effective knowledge creation in a networked community. Azechi classi-

fies the content of a message into dry and wet information [1]. Dry information primarily contains logical linguistic information and constitutes the core of a message. In contrast, wet information is mainly nonlinguistic, meta-information incidental to the contents of the message. Azechi argues that community-wide discussion for achieving some practical goal should be made only with dry information, otherwise rational discussion will be hindered due to the pathology of a group. Matsumura addresses the consensus formation in networked communities [13]. Based on social psychological experiments, he has found that (i) minority members tend to overestimate the number of other members who share the same attitude, (ii) minority members tend to underestimate the attitude of other members, (iii) minority members who underestimate the proportion of the minority's opinion tend to lose an intention to act. Such inaccuracy in cognition of opinion distribution is called the false consensus effect. These observations should be taken into account in designing discussion support systems so that useful discussions can be expected by reflecting minority opinions.

Theories of language use in interaction are relevant to establishing the common ground in collaboration. Rosenberg suggests that key issues are information integration into a common ground, the relation between linguistic channels and shared knowledge, and the mechanism of retaining shared knowledge in the common ground of different kinds of participant [17]. In the context of social learning, Marlow and Peretti explore attachment-based learning comprising response imprinting and mimicry. They have built a learning environment to test the hypothesis [12].

1.2.6 Evaluations of Social Intelligence

Social Intelligence Design is certainly an empirical study. We have to repeat the design-implement-evaluation cycle until we reach better systems.

Network Analysis is a powerful means of evaluating or comparing empirical data. It provides us with a means for calculating various aspects of a given network in terms of centrality, density or cohesion. By comparing those features from one network against those from another, we can describe the similarity and difference in quantitative terms. Fujita has conducted a field trial and employed network analysis to show the effectiveness of their community support system [5]. Fujihara has also applied network analysis to a log collected from experiments with a POC prototype [6] for several months to see if POC actually facilitates community knowledge creation [4]. He also points out that network analysis alone is not enough to evaluate community support systems, and hence it should be combined with several other methods such as the user's subjective analysis or log analysis.

1.3 Concluding Remarks

Social Intelligence Design is a discipline aimed at understanding and supporting social intelligence. In this paper, I have overviewed major issues involved in Social Intelligence Design and attempted to structure them in a coherent story. The contemporary view of Social Intelligence Design consists of methods of establishing the social context, embodied conversational agents, collaboration design, public discourse, theoretical aspects of social intelligence design, and evaluation of social intelligence.

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2. FaintPop: In Touch with the Social Relationships

Takeshi Ohguro¹, Kazuhiro Kuwabara², Tatsuo Owada², and Yoshinari Shirai²

¹ NTT-ME Corporation, Marketing HQ V, Tokyo 100-8132, Japan.
email: pih2@moon.sannet.ne.jp

² NTT Communication Science Laboratories, NTT Corporation, Kyoto 619-0237, Japan

We propose a tool called **FaintPop**. It is intended to be an alternative media that is suitable for a very light-weight, acknowledge-only, mode of communication. Furthermore, it intuitively provides, through memories of communication, a general overview of the communication activities. The tool is designed for a community, with which the sense of connectedness can be shared among members. Results from an initial experiment are reported briefly.

2.1 Social Intelligence Design for Communications

Although the IT (Information Technology) bubble is said to have burst, the Internet and IT remain essential and are experiencing continued significant advances. There are several evidences that support the trend, just to mention an example: Mobile phone services are rushing toward the 3G era in which more ubiquitous and broadband communications will be fully utilized. The trend shows that our lifestyle, as well as our society, is surely being impacted by the Internet and IT. It is hard nowadays to imagine to work, live, or communicate without the network. Now the important question is determining what design will best augment social intelligence for the network age. More specifically, we focus on the communication environment for emerging networked societies, since communication is the very basis of the societies.

In challenging the question, we first look at the problem that is currently appearing and would increase in the future. The problem, *Communication Overflow* [2.15], consists of two related subproblems. One is that our opportunities for communications are much greater than ever before. This trend is sometimes so overwhelming that our communications become segmented into pieces, that we lose the general view on our own communication activities. The other is that we do not have enough variants of network communication media to support the various communication modes common in our daily lives. For example, current network communication media seem too heavy for simply saying “Hi,” which is a frequently-used communication mode in physical environments. Using non-suitable media requires cognitive load.

The notion of “Communication Overflow” is closely related to the problem of “Information Overflow.” However, our focus is not information itself. In

other words, our primary focus is not on the “developer’s side,” which mainly addresses the tools and abilities offered by technologies. Instead, we focus on the experience of users [2.18]. In other words, our primary focus is on the “user’s side,” that mainly concerns how tools are used, in what situations, and by whom. Therefore we use the term “Communication Overflow,” to clarify that the problem is with the possible overflow on users’ opportunities and awareness on his/her own communication activities.

To answer the above problem, we proposed a new communication environment [2.14]. *Awareness of Connectedness* is the key notion for understanding the environment. Here we focus on the awareness of (the communication activities of) oneself. Moreover, to transmit and share the sense of connectedness (awareness of “connected” status with others) are also primary concern. This is contrasted to the term “awareness” used in the area of groupware, in which awareness information of the other participants involved in the current communication is the central issue, where the information is to supplement the contents of communication (e.g., [2.7]).

Two candidate tools for the environment are introduced. One is called the **Indicator**, which is intended to provide feedback of the user’s communication activities [2.4]. It provides a general overview of user’s communication activities, which is easily lost in the current segmentation of communications. The other is called **Gleams of People**, which is a simple, intuitive interactive media that exchanges the presence and statuses of users [2.16]. It is designed to be an alternative communication media which is very light-weight and suitable for the acknowledge-only mode of communication.

As the first tools for the new communication environment, both tools were designed for personal use, since the individuals’ awareness of communication and connectedness is fundamental to social communications. The aspects of communities and societies are not addressed directly by the tools, though they can be derived implicitly as participants of communications in individuals’ communication activities. However since we mostly belong and act in communities, tools that address these aspects will also be needed. Therefore, in this paper, we introduce the third tool for the communication environment.

The tool, called **FaintPop**, subsumes the functions of the two tools mentioned above, but is designed to be a media for a community. More specifically, it provides an alternative communication media that is very light-weight and suitable for the acknowledge-only mode of communication, through which the *sense of connectedness* will be shared across the community. Moreover, it provides the *general overview* of communication activities in the community. The tool works in a *suggestive* way [2.15]. That is, it does not provide logical analysis such as comment chains or statistics; Instead, a general view is provided that offers a more intuitive but vague picture of what’s is going on in the community. In this way, the tool will retain the social relationships among the community members.

2.2 In Touch with the Social Relationships

We incorporated a scenario-based technique [2.3] in designing the tool.

The scenario: *This snapshot shows my old friends. Most of us live far apart, but our friendship might remain. Sometimes I feel like contacting them, but find it hard to do so. Isn't odd to make a phone call or to write a letter without any "important" business? What I want is mere a slight touch that we still are the friends; Just a faint sense of connectedness would suffice. I wonder if I can do this using just this snapshot.*

FaintPop implements this scenario; It is a media for sharing the sense of connectedness in a community. Messages exchanged using this media are a sort of *things that not so important to talk to, but worth expressing*. That is, the communication established by this media is not about important business matters, but about feelings which are very important in social relationships. The communication does not involve written or spoken language, the more intuitive technique of *touching* is employed. Moreover, memories of communication are summarized and represented graphically in an intuitive way. It gives the users a *general view* of what's going on in the community.

Figure 2.1 shows two FaintPop prototypes. It is a hardware device shaped to resemble a photo frame. Each member of the community has his/her own device, and all pictures are the same initially. All of them have networked. Instead of using real photographs, small pictures (or icons) of faces of all members of the community (possibly extracted from the original photo) are displayed. Members can communicate each other by touching the images/icons of friends. Written or spoken language is not supported, because in case of contents-oriented mode of communication where such languages are involved, conventional media such as e-mail and phone are more suitable. Instead, FaintPop is oriented to the very light-weight, acknowledge-only mode of communications, in which to notify some content is not the main objective but to share the sense of connectedness is the main purpose.

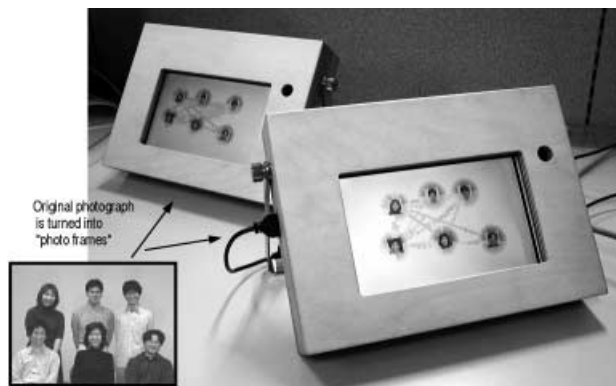


Fig. 2.1. FaintPop prototype

Three touching types are provided. A *tap* to represent neutral feeling, a *pet* to represent more positive feeling, and a *hit* to represent rather negative feeling. Due to the limitation of the device, these three types are currently implemented as a click, a long click, and a double click, respectively. Most users easily learned to input the right type by touching the screen with his/her finger. Our current design choice is to offer just these three types. Whether these three are enough remains to be confirmed. Some studies indicate that six or more basic emotions exist [2.1]. However some of these emotions (e.g., fear and anger) are not appropriate for the light-weight, acknowledge-only mode of communication. Furthermore, providing too many types would confuse users, complicate the interface, and conflict with the objective of the media.

Touching a picture of a friend means that one of the three feelings are passed to that friend. The touch is encoded and distributed (via the network connections) to all the members in the community, so that all members can share what is going on in the community. The sending of a touch is displayed in all member's screen as an animation effect: A small ball travels from the sender to the recipient, with different colors and speeds according to the three types of touching. The picture of a friend who received a message with positive (negative) feeling blinks larger (resp. smaller) for a while. For neutral feeling, the picture oscillates for a while. Touching his/her own picture means to broadcast a message to all community members —In other word, the user calls out the community in that feeling. Figure 2.2 shows the animation effect that a user broadcasts a message with negative feeling.

The tool is modeled after a photo frame so that it can be placed and embedded naturally in daily lives. Therefore, the interface should not annoy the user such as flashing the whole screen. However such non-disturbing design has a drawback that the user possibly miss the communication that being held. One solution is to use a faint sound to indicate that some activity related to the user is occurring (for example, a message from another user is arrived). Different sounds are used according to the three types of messages.

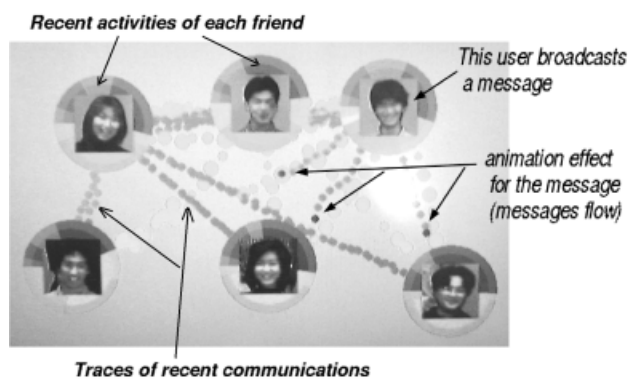


Fig. 2.2. Screen image of FaintPop. A broadcasting message, traces of communications and recent activities of users are shown.

Another technique is to provide memories of communications. In the background of pictures, traces of animation effects, which corresponds to the communications held, are left. Moreover, the informations that which members have been actively communicated recently is indicated by the changing color of the bulls-eye surrounding the picture of the friends; It is represented as a pie chart that indicates which types of messages are sent by the user recently (Figure 2.2). These memories gradually disappear with time. This provides a general view of communications in the community. The feature well suits the nature of the tool; One of the typical use case is that the user would glance at the “photo frame” occasionally and notice that something had happened among the friends. Therefore the tool has the aspect of asynchronous communication media, in addition to the aspect of synchronous communication by touches. Hence, memory retention periods range from hours to a day, longer than those of most (synchronous) communication media.

The touches that users make are not only visualized as animation effects and memories of communication but affect the default locations of each picture of friend. **FaintPop** holds the parameters of closeness, which are naturally asymmetric, between the friends. When the user touches a friend positively (negatively), the acquaintance parameter from the user to the friend is increased (resp. decreased). Then the picture of the friend is moved closer to (resp. apart from) that of the user. Therefore, the locations of pictures displayed on a user’s “photo frame” represent the closeness from the user to the friends. A single touch triggers just a slight change. Again, this is the long term effect as so is similar to the memories of communication.

The user can know the closeness between friends (or the closeness from friends to the user) by dragging the picture of friends (or self). When the picture of friend A is dragged to that of friend B, the picture of friend B responds. If the acquaintance parameter from B to A is high (low), the picture of B moves close to (resp. apart from) the picture of A. Note that the acquaintance parameters are asymmetric: Dragging the picture of B to that of A may cause different move. This effect ends when the user stops the dragging, and all the pictures are returned to their default locations. The dragging itself do not generate a message nor is shared among the friends, but the information that the user performed dragging is distributed. It is shown in the activity summary (pie chart) surrounding the picture of the user.

Privacy and one-to-one communication issues are important but not addressed directly by this media. It is because our main focus is to provide an alternative communication media that will allow the sense of connectedness to be shared in the community. For one-to-one communication, we have introduced another media called **Gleams of People** [2.16]. It might be desirable to integrate these media in the future.

2.3 Initial Experiment

To verify whether the basic objectives of the tool were accomplished, we conducted a preliminary experimental study. To match our scenario (section 2.2), 6 subjects of similar ages who knew each other, that reside in different office locations and belong to different work teams, were selected from our laboratory members. Before the experiment, the subjects were instructed the basic usage of the tool. However, the objective of the tool, as well as when and in what purpose they were supposed to use the tool, was not explained. A traffic log of the tool was collected during the experiment. After the one-week experiment, subjects were asked to answer a questionnaire, mainly on at what occasions they sent messages, and with what they expected to communicate.

It was well accepted as an alternative communication media for a community. Communication using FaintPop was frequent than e-mail and phone calls: An average of 13.4 messages per subject per day. Moreover, it was reported that subjects would like to use a media like FaintPop with close, intimate friends, while they wouldn't with non-close persons or bosses. Although the objective of the tool and our scenario were not instructed, subjects understood the nature and objective of the tool through the experiment.

FaintPop was used as a very light-weight media for an acknowledge-only mode of communication. Subjects sent single message mainly to express casual greetings and simple replies (acknowledgment) to the message received. Broadcast messages were used mainly to express friendly greetings when their status change (e.g., "see you tomorrow"). Figure 2.3 shows the daily usage of FaintPop. In 10:00 period, the largest number of broadcast messages were sent: Subjects issued friendly greetings, saying good morning to the community. Subjects actively dragged the picture of friends in 15:00 period: They were between tasks, and their moods changed (or they were trying to change). In 17:00 period, subjects actively sent single messages, trying to change his/her mood by expressing casual greetings. The questionnaire indicated that *"Around 17:00, I felt sympathy with friends that they also were taking a pause between tasks, because many friends actively used the tool."*

The general overview of the communication activities was accepted positively. Memories of communications, both the pie charts of recent activities and the traces of communications, were accepted positively. However detailed opinions varied. For example, some subjects reported that too many traces lasted too long, others reported that traces disappeared too quickly. Therefore, there is room to refine the representation.

It can retain the social relationships among the members of the community. The questionnaire replies indicated a slight improvement in the sense of closeness among the subjects, but it was not evident. However one subject reported: *"I often used FaintPop when I heard a sound from it. I felt the sense of connectedness through the sounds, then confirmed the situation by watching the screen. Now the experiment is over and I miss the sounds."*

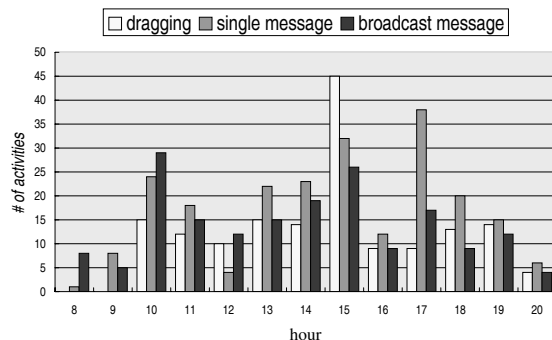


Fig. 2.3. Total number of activities during the one-week experiment

2.4 Conclusion and Related Works

A tool called FaintPop is introduced, to demonstrate one answer to the problem of communication overflow. It is a media designed for a community, with which the sense of connectedness can be shared among members. It is intended to be an alternative media that is suitable for very light-weight, acknowledge-only mode of communication. Furthermore, it provides, through memories of communication, a general overview of the communication activities in the community. Results from initial experiment using the media are reported. It is suggested that the basic objectives of the tool are achieved. More long-term experiment will reveal the details on whether its objectives are accomplished and how people accept and use (or refuse) the media.

For communities and groups, several visualization tools for communications have been studied [2.5, 2.10, 2.11]. However, they are sometimes oriented towards the logical, analytic aspect of the activities, or the communication media and the visualization are separated. On the other hand, FaintPop is intended to be a communication media that also offers intuitive visualization of (memories of) communication. There are several researches that try to support communities [2.8, 2.9, 2.13]. These studies are closely related to ours, however, most focus on the contents-oriented mode of communication.

Several studies that use devices modeled after a photo frame are found. Kodak and StoryBox Network (www.storybox.com) started a service named *Smart Picture Frame*. While the sense of connectedness seems to be in its view, it merely shares pictures, not being a communication media nor using touches. In [2.12] the concept of *digital picture frame* is introduced. It tries to provide the visualization of everyday life activities of the person in the picture by using icons on the frame. It intends to foster relationships between distributed families, and so is closely related to *Familyware* [2.6]. Though the objective is close to ours, their main concern is sensing and visualizing the status of a member. A light-weight communication media that uses photo frames and feathers is proposed [2.17]. *inTouch* is also a light-weight media using touches [2.2]. However, these works are basically for one-to-one communication, and memories of communication are not well supported.

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3. From Virtual Environment to Virtual Community

A. Nijholt

University of Twente, Department of Computer Science, PO Box 217, 7500 AE Enschede, Netherlands

3.1 Introduction

We discuss a virtual reality theater environment and its transition to a virtual community by adding domain agents and by allowing multiple users to visit this environment. The environment has been built using VRML (Virtual Reality Modeling Language). We discuss how our ideas about this environment changed in time by adding more facilities to it and by paying more attention to potential users. Rather than a goal-directed information and transaction system, the environment is evolving into a virtual community where differences between visitors and artificial agents can become blurred. Before going into a description of our own environment and its development we survey the research areas that now allow the building of 3D embodied and animated agents that show intelligence and personality and that can inhabit our environment.

3.2 Towards Multi-user Virtual Worlds

The first networked virtual worlds were text-based. They became known as MUDs (Multi-User Domains) and they allowed communication between users and access to a shared database with text descriptions of users and objects. In these environments the personality of a user shows in the contents and the style of the text utterances the user produces, his turn taking behavior and more generally the moods (as they show) and attitudes towards the community that can develop in such environments. Graphical multi-user environments were introduced in the 1980s. In a typical setting we have a background image showing the entrances to several locations or rooms in the environment or we are in one of these 2D locations and we can choose one of the other visitors (or all of them) to talk to. Typically, visitors can present themselves by choosing an avatar (a 2D object) and its predefined animations. These animations are simple (a waving gesture, a jump of joy, . . .). Most interactions are text-based, by using chat windows and text balloons that appear above the head of avatars that take part in the discussion.

With the advent of VRML, virtual worlds could be designed for Worldwide Web. Rather than for chatting, the worlds were meant to be explored, to explain or to allow the simulation of a particular activity in which the visitor was involved. Virtual reality applications were already there and rather than consider distributed virtual reality as a technology to design communities it was explored for all kinds

of applications. Virtual worlds intended to meet other people entered the arena. In these worlds multiple visitors can share the scenes. In the more advanced worlds users can change parts of the world and can have sophisticated visual representations that can interact without being restricted to predefined gestures. An avatar can be made to resemble the human user by photographic means.

The worlds that we consider may have collision and gravity features that become visible in the movements of avatars. There can be real-time voice communication and in addition there can be lip-sync facial gestures. Despite adding such features, there remains an enormous gap when we compare the capabilities of the avatars and talking heads with those of the humans they represent. One way to close this gap is to give the human user the ability to control the avatar in a much more detailed way. One possibility is to have them explicitly controlled online by the user and captured from verbal and non-verbal input or from body movements. Also, in addition to the avatars that represent humans we can add domain avatars to the environment to increase the sense of reality. They should be animated, but preferably there should be possibilities to give them personality and capabilities to act on their own or on behalf of a user of the avatar or owner of the environment. That is, they need appropriate internal modeling to allow autonomous behavior.

3.2.1 Interacting Embodied Personalities

Agent technology is a research field that emerged in the 1990's and that can be considered as a field in which actors are developed, although not necessarily in the context of human-computer interaction or virtual communities. Without going into details and especially controversial details, we want to mention properties of software modules that are generally assumed to be present before being 'allowed' to talk about them as agents: autonomy, reactive and proactive behavior and the ability to interact with other agents (or humans). For an agent to act appropriately in a domain it has been useful to distinguish beliefs (what the agent regards to be true, this may change in time), desires (the goals the agent has committed himself to) and the intentions (short-term plans that it tries to execute).

Believability is a notion that has been emphasized by Joseph Bates, again in the early 1990's. An agent is called believable, if some version of a personality shows in the interaction with a human. Two main theories on personality which can be used to design believable agents are trait theory, where personality is a set of psychological traits that characterizes a person's behavior and social learning theory, where appraisal of the situation and the individual's history are taken into account. Main requirements for believability are (Loyall [8]): personality, emotion, self-motivation, change, social relationships and consistency of expression.

When we zoom in on the role of emotions, it should be mentioned that there are many subtleties involved when conveying them. Cartoon characters are allowed to exaggerate, giving more cues to the observer. Emotional cues shouldn't be in conflict with contextual cues. Emotional cues should be consistent during interaction; nevertheless they may change when interaction has taken place with the same user during a longer period, in time. Computational models from which emotional behavior can be generated exist, but are not based on well-developed theory. There-

fore, rather than having emergent emotional behavior based on an agent's cognitive appraisal model, we see applications in prototype (learning) environments with preprogrammed emotional display.

Now that we have discussed reasonable, social, intelligent, believable and, indeed, whatever kind of cognitive behavior, it is time to consider the role of embodiment. Embodiment allows more agent multimodality, therefore making interaction more natural and robust. Several authors have investigated nonverbal behavior among humans and the role and use of nonverbal behavior to support human-computer interaction. See e.g. (Cassell [1]) for a collection of chapters on properties and impact of embodied conversational agents (with an emphasis on coherent facial expressions, gestures, intonation, posture and gaze in communication) and for the role of embodiment (and small talk) on fostering self-disclosure and trust building. While the previous investigations we mentioned can be understood to emphasize the cognitive viewpoint of embodiment, we can as much emphasize the possibility of an embodied agent to walk around, to point at objects in a visualized domain, to manipulate objects or to change a visualized (virtual) environment. In these cases the embodiment can provide a point of the focus for interaction. From a technical point of view, extremely much has to be done on human-like (from a physical and cognitive point of view) agent behavior. From a domain point of view it has to be decided when and why such behavior is useful.

Our next step is from embodiment to virtual humans. A list of research topics involved includes natural looking movement and deformation of visible body surface, animation of skeleton, hands and face, hair, skin and clothes representation, natural looking walking and grasping animation and, very importantly in the view of the previous topics, behavioral animation which strives at giving character and personality to the animation. This list of viewpoints can be complemented with viewpoints from cognitive and perceptory sciences. Virtual humans have to act in virtual environments where a visual, an auditory and a haptic/kinaesthetic environment intersect.

3.2.2 Embodied Personalities in Virtual Worlds

Agents are finding their way in virtual environments. The first applications of embodied agents can be found in training, simulation, education and entertainment. These environments may include a single agent with which the user can interact, but the user itself, or part of the user, can be included in the environment. In team training we can have several agents in the environment or several users are represented in the environment. Research into crowd modeling also studies the behavior of groups of people in virtual environments.

However, apart from these applications we also see developments where 2D and 3D extensions of chat worlds and digital cities become inhabited by embodied agents, both as representations of visitors and as autonomous domain agents. In the near future we can expect that companies, families or groups of people that share interests have the opportunity to design and use such environments. Below we mention a few projects in which these future developments become visible.

Several impressive research systems employing animated pedagogical agents have been built and are in a process of further development. Embodied pedagogical agents can show how to manipulate objects, they can demonstrate tasks and they can employ gesture to focus attention. As such they can give more customized advice in an information-rich environment. Lester et al. [7] use the term deictic believability for agents that are situated in a world that they co-inhabit with students and in which they use their knowledge of the world, their relative location and their previous actions to create natural deictic gestures, motions, and utterances.

One example of an environment that employs embodied agents is the Soar Training Expert for Virtual Environments (STEVE, see Johnson et al. [5]). This is an immersive 3-D learning environment with a virtual agent called Steve. Steve demonstrates how to perform a physical, procedural task. It is a typical example of an environment where a student can get hands-on experience. Due to the student's head-mounted display, Steve's perception module knows about the student's position in the virtual world, about the student's line of sight and which objects are in the student's field of view. Steve has been designed to support team training.

A second example we want to mention is a BodyChat (Vilhjalmsson [14]), a research environment on conversational embodied agents. That is, there is not really a task to be performed or learned. People exchange information and chat. In this environment several users can have a conversation using the keyboard while their cartoon-like 3D animated avatars display corresponding salutations and turn taking behavior. They look away during planning an utterance, they back-channel feedback and facial expression and look to the next speaker when ending. Watanabe [15] reports about similar research. Another system by Vilhjalmsson, called Situated Chat is in development. This system also animates avatars in an online graphical chat environment. However, since it knows about the shared visual environment the generation of avatar movements can include referring gestures when making implicit or explicit references to the environment during the conversation.

As a third range of examples we look at systems that have become known as interactive theater, where players connected by a network can take part in a performance as actors. There is a host server for the producer and there are client computers for the performers. The latter are represented as avatars in the virtual environment and with motion capture systems (cameras or sensors) avatar movements reflect player actions. Gestures, touch and facial expressions of the players can be tracked and given to the animation algorithms. The virtual stage may have actors that are provided by the theater and that show autonomous behavior according to some action patterns. They have a role, but the way they perform this role is also determined in interactions with the human players and their alter ego avatars. See Takahashi et al. [12] and Tosa et al. [13] for examples of interactive theater.

3.3 Building a Theater Environment

The main theater building in our university town is called ‘Het Muziek Centrum’. It includes the usual rooms: performance halls, dressing rooms for artists, recreational locations (for the audience and performers), wardrobes, etcetera. It also includes a music academy. There are also some other theater buildings in the town. At this moment some of the buildings, their surroundings and the streets leading from one location to the other are being modeled in VRML and Java 3D. The virtual theater was built according to the design drawings of the architects of the real building. Originally the environment was built around an already existing natural language dialogue system that provides information about theater performances and that allows reservations to be made. In the virtual environment the dialogue system has been assigned to a visualized embodied agent. Once we had this agent and extended the environment, there grew the need to add other agents that were able to help the visitor. This raised our interest in having these agents communicate with each other as well and to endow them with some form of autonomous behavior. Rather than towards a goal-directed information and transaction system comparable to a voice-only telephone information system, the environment is now evolving into a virtual community where differences between visitors and artificial agents become blurred and where research topics show a wide variety including assigning personalities and emotions to artificial agents, usability studies involving a navigational assistant, formal specification of (interactions in) virtual environments and reinforcement learning for agents in this multimodal environment to increase their autonomy.

When we enter our Virtual Muziek Centrum, we see the information agent called Karin, waiting to tell us about performances, artists and available tickets. Visitors can explore this virtual environment, walking from one location to another, looking at posters, clicking on objects and so on. Karin can be asked natural language questions about performances in the theater. She has access to a database containing all the performances in the various theaters during the current season. Karin has a 3-D face that allows simple facial expressions and simple lip movements that are synchronized with a text-to-speech system mouthing the system’s utterances to the user (see Nijholt & Hulstijn [9] for details). Other agents have been introduced in this environment. For example, a navigation agent, that knows about the geography of the building and that can be addressed using typed in natural language utterances. The visitor can ask the agent about existing locations in the theater. When the request is understood, a route is computed and the viewpoint in the world is guided along this route to the destination. The navigation agent has not been visualized as a 3D embodied agent.

A Java based agent framework has been introduced to provide the protocol for communication between agents and the introduction of other agents. For example, why not allow the visitor to talk to the map of the seats in the main concert hall or to a poster displaying an interesting performance? In fact, we can have a multitude of potential and useful agents in our environment, where some just trigger an animation, others can walk around and others have built-in intelligence that allows them to execute certain actions based on interactions with visitors. Some of the 3D avatars that live in our environment have not yet been incorporated in the frame-

work in a way that visitors can communicate with them (a baroque dancer, a piano player). We have been experimenting with embedding our environment in a multi-user shell (Reitmayr et al. [11]) that allows to entertain multiple visitors that can make themselves visible to each other as avatars (VRML objects). These avatars move along with the visitor, but they can also be assigned animations, intelligence and interaction abilities. Hence, we can have different human-like agents. Some of them are autonomous embodied agents standing or moving around in the virtual world and allowing interaction with visitors of the environment. Others represent human visitors of the environment. We want any visitor to be able to communicate with autonomous agents and visitors, whether visualized or not. That means we can have interactions between agents, between visitors, and between visitors and agents. This is a rather ambitious goal which cannot be realized yet completely.

3.4 Interacting about Performances and Environment

How does interaction between domain agents and visitors take place? We decided to introduce a model of natural language interaction between Karin and user that is rather primitive from a linguistic point of view, but sufficiently intelligent from a practical and pragmatic point of view. This natural language understanding system mediates between the user and a database containing information about performances, artists and prices. Although the 'linguistic intelligence' is rather poor, the outcome of a linguistic analysis can be passed on to pragmatic modules that produce relevant system responses in the majority of cases. The system prompts make users adapt their behavior to the system. Karin presents her information using text-to-speech synthesis and lip movements. When there are too many performances to read out, she presents a table and draws the user's attention to this table using eye movement and a natural language utterance. The dialogue system can interpret and generate references to items in this table.

It may be clear how to address Karin. However, visitors may want to address other domain agents and agents that represent users. As mentioned, this is work in progress. We are following several approaches to solve this problem. They are related and can be integrated since all of them are agent-oriented and based on a common framework of communicating agents. In addition, we have built this framework in such a way that different agents with different abilities can become part of it: a simple animated piano player, a baroque dancer that 'understands' the music she is dancing on, Karin who knows about theater performances, and a navigation agent that knows about the geography of the building.

Developing navigation agents leads to a number of questions. How can we build navigation intelligence into an agent? What does navigation intelligence mean? How can we connect this intelligence to language and vision intelligence? Visitors of our environment are language users and, moreover, they know and interpret what they see. There is a continuous interaction between verbal and non-verbal information when interpreting a situation in our virtual environment. This interaction and the representation and interpretation of sources and then the generation of multimedia from them are among the main topics of our research.

We very much follow Darken & Silbert [3] in our approach to navigation. To assist the visitor in navigating through our virtual theater, we have added both a map and an intelligent navigation agent. The visitor can ask questions, give commands and provide information when prompted by the agent. This is done by typing natural language utterances or by moving the mouse pointer over the map to locations and objects the user is interested in. On the map the user can find the performance halls, the lounges and bars, selling points, information desks and other interesting locations and objects. The current position of the visitor in the virtual environment is marked on the map. While moving in VR the visitor can check his or her position on this map. When using the mouse to point at a position on the map, references can be made by both user (in natural language) and system to the object or location pointed at. We have annotated a small corpus of example utterances that appear in navigation dialogues. An example of a question is: "What is this?" while pointing at an object on the map, or "Is there an entrance for wheel chairs?". Examples of commands are "Bring me there." or "Bring me to the information desk." Examples of short phrases are "No, that one." or "Karin." From the annotated corpus a grammar was induced and our unification-type parser for Dutch can be used to parse these utterances into feature structures. Three agents communicate to fill in missing information in the feature structure and to determine the action that has to be undertaken (answering the question, prompting for clarification or missing information, displaying a route on the map or guiding the user in VR to a certain position). The navigation agent, the dialogue manager and the Cosmo Agent do this in co-operation. Not yet implemented is the possibility that not only the position but also what is in the eyesight of the visitor is known. This will allow interpretation of references to objects that are visible to a visitor.

3.5 Towards a Theater Community

The length of this paper does not allow a comprehensive survey of all the problems we have to deal with when we want an agent-oriented design of our environment and have it inhabited by agents that can be embodied, have intelligence and personality and can communicate with each other and with agents that represent visitors. To design and maintain an environment like that we need some uniformity from which we can diverge in several directions: agent intelligence, agent interaction capabilities, agent visualization and agent animation (cf. Nijholt & Hondorp [10]). Standards are needed to allow frameworks for communication, internal modelling, and animation of embodied agents. These standards should also address issues concerned with multi-user and multi-developer environments.

In Egges et al. [4] we introduce an approach to the internal modelling of agents we think we can use in our multi-agent and multi-user environment. Our approach discussed there, is limited, but nevertheless allows modeling of 'intelligence' in terms of beliefs, desires and plans, and possible extensions to the modeling of emotions and an agent's knowledge about movements, postures and non-verbal communication. Our current emotion research is reported in Kesteren et al. [6] and Bui et al. [2].

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4. Collaborative Innovation Tools

John C. Thomas

IBM T. J. Watson Research
PO Box 704, Yorktown Heights New York 10598 USA
jctomas@us.ibm.com

4.1 Importance of Collaboration: Practical and Scientific

We live in an increasingly interconnected world. In reflection of this trend, the field of human-computer interaction has shifted focus from individuals to teams and large organizations [35]. From a scientific perspective, we learn most about the object of study during transitions. Thus, a learning test is generally more diagnostic of brain function than a test of stored knowledge; a glucose tolerance test tells us more than a resting blood sugar level; a stress test reveals more about the heart than does resting heart rate. Similarly, this century's rapid transitions should allow us to learn a great deal about collective human behavior. At the same time, we face enormous planetary problems including global fouling of the ecosphere, inequity in economic opportunity, increased chances for catastrophic disease, and international terrorism. These problems arose with current approaches and limitations to collaboration and will only be solved via breakthroughs in collaboration.

From a more mundane viewpoint, similar challenges exist today for large, international organizations. For instance, the world is changing more quickly but creative design ability has not increased. As a result, there is a widening gap between the degree of flexibility and creativity needed to adapt and the capacity of individuals and organizations to do so [12]. Design problems are often extremely high leverage for organizations. For instance, errors in design, whether in software, drugs, business processes, or automobiles are extremely costly. Conversely, effective and innovative designs can be extremely lucrative; are a hallmarks of long-lived companies [7, 10]. Even a modest increase in the ability of organizations to create more effective designs could greatly increase profits in existing markets and create whole new markets. Increasing design effectiveness will require collaboration breakthroughs.

Human beings evolved natural language as a method of collaboration among small groups of people who generally shared context, goals, experience and culture. Under those circumstances, sequential human speech served fairly well, e.g., the telling of stories for sharing experiences [34]. However, unaided speech is not well-suited to large-scale collaborations; particularly not when the people involved have vastly different assumptions, cultural backgrounds, goals, contexts, experiences and native languages. We have not yet invented an entirely effective

replacement of natural language for large, diverse groups though storytelling can be useful in bridging gaps among groups when incorporated into the appropriate process [3, 4, 37]. Can we further extend such techniques to facilitate communication among larger, more diverse groups? Or, should we limit such interactions to "dry" interactions [2]?

One of the special challenges offered by collaboration today is that often it involves remote participants; sometimes, worldwide[25]. In many conversations and papers, an implicit assumption is that remote collaboration is limited by bandwidth alone and that the current superiority of face to face over remote collaboration will disappear once bandwidth becomes large enough. Such an analysis overlooks two additional and potentially quite important aspects of face to face collaboration.

First, face to face collaboration allows people to see and experience the physical and social context of their collaborators. Perhaps they see the building where others work; try the same food; find out whether they work in a quiet or noisy environment; what the moods are of those that pass by in the hallways. Second, sharing an actual physical space allows the possibility of much deeper interaction and that possibility may well affect trust even if the possibility never materializes. Consider two rather extreme examples. First, two people sharing a physical space may be subject to a natural disaster such as an earthquake and one may save the life of the other. Although obviously a very low probability event, the mere possibility may well put people's perceptual and emotional apparatus into a heightened state of arousal. Second, if two people share a common physical space, one could physically injure the other. Since A's trust of B is enhanced by situations wherein A could hurt B but in fact, does not, the typical face to face interaction may enhance trust in just this way.

It is not only the medium and context of communication that impact collaboration, but also the content. In particular, we argue that expressive communication may offer an opportunity for collaborators to gain more comprehensive models of each other than instrumental communication alone. Instrumental communication is communication that is required to accomplish the current task. Expressive communication is communication that tells about the communicator as well as the subject; it is communicated more because the communicator wants to than because they need to.

Zheng, Bos, Olson, and Olson [38] showed that collaboration and trust can be, in effect, "jump-started" with social chitchat. Stories can also help people develop more trust than the exchange of information per se. A story is not simply an objective recounting of events; it always implies a number of revealing choices. The storyteller chooses which events to talk about; where to start; tone; viewpoint; which details to describe and so on. Through such choices, the storyteller inevitably reveals themselves as well as the subject.

So long as collaboration proceeds along predictable lines, models built from expressive communication may be unnecessary. But, if standard procedures break down, then collaborators who have developed more complex models of each other will be able to react more effectively and efficiently as a team. Of course, there is also a danger here. As perhaps hinted at by Azechi [2], stories might also reveal

characteristics of the storyteller that other collaborators might find quite negative while purely instrumental communications are unlikely to do so.

A challenge for knowledge socialization is to determine the conditions under which it is better to keep communications “dry” or “instrumental” and when it is desirable to include more expressive or “wet” modes of communication. If the latter is necessary, we also need to develop methods of progressive disclosure that minimize friction and maximize empathy.

4.2 New Technological Possibilities

Recent advances in computing power, interface technologies, bandwidth, storage, and social engineering provide many possibilities for novel solutions to large-scale collaboration may be designed, tested, and improved. In the “real world” effective on-line collaboration systems both at a distance [16] and face-to-face [17], are already being facilitated by technology. We believe further advances can be made by incorporating creativity aids, suggestions for processes [33], and by providing tools for alternative representations [31].

Failure to innovate is not random, but can be ascribed to one of several main difficulties: 1. Individuals or groups do not engage in effective and efficient processes of innovative design. 2. The necessary skills, talents, and knowledge sources are not brought to bear on the problem. 3. Appropriate representations of the situation are not used. Laboratory [6, 15, 29] as well as field research [24, 36] has established that the major process difficulties are mainly due to a limited number of preventable errors.

An appropriate overall structure may facilitate groups through steps of innovation and help guide these separate steps; distinct guidelines are appropriate within each of these steps [28, 33]. A common problem is that people typically fail to spend sufficient time in the early stages of design; viz., problem finding and problem formulation [27]. A common failure during a specific stage of innovative design is that people often bring critical judgment into play too early in the idea generation phase of problem solving. As another example, unlike Newell and Simon's [22] normative model of ideal problem solving, in fact, people's behavior is path-dependent and they are often unwilling to take what appears to be a step that undoes a previous action even if that step is actually necessary for a solution [29].

Regarding the second issue (bringing to bear necessary skills, talents and knowledge sources), while software tools cannot fully substitute for human experts, evidence suggests that individuals have a large amount of relevant implicit knowledge which they often will not bring to bear on a problem and that giving appropriate strategies [29], or knowledge sources [30] can help.

Regarding the third issue of appropriate representation, controlled laboratory experiments have shown that subjects did significantly better, for example, in a temporal design task when they used a spatial representation; yet, very few subjects spontaneously adopted such a representation [6]. The impact of good representations, however, is not confined to laboratory demonstrations. Speech research

advancements accelerated greatly when waveforms were largely replaced with speech spectrograms and Feynman diagrams allowed breakthroughs in atomic physics. By providing people with a variety of potential representations and some processes to encourage the exploration of various alternatives, we could probably improve performance significantly.

Advances in speech recognition, combined with natural language processing and data mining raise the possibility of large-scale real time collaborations. Speech recognition can turn raw speech into text. Statistical techniques can automate the formation of "affinity groups" that share various interests, values, or goals [23]. Speech recognition, in this context, need not produce perfect transcripts of what is said but only transcribe enough content to enable natural language processing software to cluster segments of text.

Additional benefits stem from a speech to text to clustering system. In the past, conversations were transient. There was no "objective" evidence of their content or structure. It often happens, e.g., in a group meeting that the first person to raise a new idea is not recognized as having done so. Instead, the second or third person to mention the idea is often credited with it, quite possibly because the first mention is unassimilable by the current mental model of the listeners but causes a change in mental models so that a subsequent mention is comprehensible. The more general point is that computerized records of group meetings and larger scale collaborations allow the possibility of feeding back to the participants various visualizations of behavior, making the computer an active participant in group communication [32]. In conjunction with effectiveness metrics, such feedback mechanisms may allow groups to improve effectiveness.

At IBM, we recently engaged in a corporate-wide experiment called "WorldJam" wherein all IBMers worldwide were invited to a three-day electronic meeting to discuss ten issues of interest to IBMers including employee retention, work-life balance, and working remotely. Over 52,600 employees participated and posted over 6000 suggestions and comments.

Each topic had a moderator and facilitators. Each moderator, in turn, had been asked to assemble a topic-knowledgeable "Board of Advisors" to provide references, websites, and other relevant materials ahead of time as well as participation during the on-line conference. In addition, the set of moderators and facilitators communicated with each other through a system called "Babble" which was designed, developed, and deployed at IBM Research. The Babble system blends synchronous and asynchronous text communication. Individuals in the system are represented as colored dots. The position of a dot within a simple visualization called a "social proxy" allows each participant to quickly see who else is present and which topics are being discussed. When a user of the system types an entry or scrolls through recorded discussion, their dot moves to the center of the social proxy for that topic. Several "Babbles" are now active within IBM including one for "Community Builders"; that is, people in various organizations throughout IBM interested in the process, tools, and methods for community building; "KM Blue" which includes a similar cross-organizational group interested in knowledge management and "Designers" which brings together people whose primary professional identification is as a designer. In the case of WorldJam, Babble enabled the moderators and facilitators to trade best practices and engage in joint problem

solving in a timely manner. Additional information about the features, functions, design rationale for and empirical studies of Babble is available in [13, 14].

In earlier work, we showed that the introduction of problem solving aids to break set increased performance and creativity [30] and that instructions to take on multiple viewpoints increased problems found in heuristic evaluation of a software design [11]. The use of multiple viewpoints has been quite consciously used by the Iroquois (and other cultures) for thousands of years [36]. Other writers on creativity have suggested similar methods [9, 28].

4.3 Work of the Knowledge Socialization Group

The work of our own group obviously relates to a tiny area of the vast space outlined above. Our work comprises several interlaced threads. In one thread, we are conceptualizing, designing, and building tools to support the creation, capture, organization, understanding, and utilization of stories as a method for groups to build and share knowledge. In the "Value Miner", e.g., natural language processing methods are used to find values as expressed in text. This could be applied to conversations, documents, and web-sites as well as stories. The Value Miner finds value-related words and phrases and tries to categorize these. A related, "Point Of View" tool shows the value similarities and differences of participants. We are also working on story visualizations aimed at helping individuals and groups create, understand, and find stories relevant to a situation at hand. For example, in one line of development, we are showing timelines of plot points and character development. In another line of representation research, we show a top level view of the kinds of attributes that are used to describe characters. By clicking on a top level view, the user may zoom onto the value associated with that attribute and ultimately to the underlying text. In addition to visualizations, there are guidelines and measures based on known heuristics of story writing that can be incorporated into groupware [18, 21].

In order to provide a common underpinning for the various story related tools that we have developed, we have proposed a first pass at a "StoryML"; that is, a markup language specifically geared toward stories. In this representation, there are three different but related "views" of story: Story Form (what is in the story); Story Function (what are the purposes of the story); and Story Trace (what is the history of the story). In turn, the Story Form can be broken down into dimensions of Environment, Character, Plot, and Narrative. The idea of the StoryML is that it is expandable according to purpose. For some purposes, the user (e.g., a student studying mystery plots) may be satisfied with minimal detail concerning Function and Trace but need to expand certain aspects of the Story Form in great detail. In another context, a different user (e.g., a historian comparing certain themes across time and cultures) might have a very high level view of Story Form and Story Function but want to provide a detailed description of Story Trace. At this point, the meta-data in StoryML must be supplied by a knowledgeable human being.

Once a base of potentially useful stories becomes large in any one collection or domain, it can become a challenge to find the "right" story or stories. If one is

looking for stories with particular objects, people, or places in them, "keyword in context" searches are generally sufficient. But, if one is looking for stories about activities, a more subtle approach is required. In response to this challenge, we have developed a script-based story browser. The "script" is a default set of parameters about an activity; it may specify roles, goals, objects, and a sequence of events. In the story browser, a user may choose an activity and find stories related to that activity or related activities through a combination of searching and browsing. Although this activity-based search works at a higher level of semantics than typical searches, in many cases, a person is searching for a story that illustrates a particular kind of very abstract point and even the particular activity is not that important. For instance, the story of Odysseus hiding his warriors in The Trojan Horse may be applicable in a wide variety of domains such as disease control or computer security. In such cases, to find stories that are potentially applicable, we really need a system based on abstract planning and problem solving strategies. In our lab, Andrew Gordon [20] has developed such an ontology for abstract planning and problem solving by interviewing experts and reading strategy books in a wide variety of domains and then formulating these strategies in abstract terms. In the next step, these terms can be used to categorize stories according to the strategies that are utilized. This will enable individual problem solvers, educators, and teams to find stories that are potentially applicable to improving specific situations or solving particular problems.

We are also engaged in attempting to extend the architect Christopher Alexander's [1] concept of a Pattern Language to stories. A Pattern Language consists of a lattice of interrelated patterns. Each pattern has a Title, a description of a context in which a problem is likely to occur, a description of opposing forces, and the basic outline of a solution. A pattern also often contains a diagram illustrating the basic solution, and may contain references or other evidence about its efficacy. Each pattern also includes links to higher level and lower level patterns. The notions of patterns and A Pattern Language have been applied to a variety of fields besides architecture including object-oriented programming [19], project structure [8] and human-computer interaction [5]. Typically, a Pattern Language is developed by a community of practice as a way to create, organize and reuse knowledge.

Our attempts to provide additional knowledge sources are focused mainly on teaching stories [34], particularly during specific stages of problem solving. For example, the story "Who Speaks for Wolf" by Paula Underwood [36] is a story especially well-suited to either problem formulation or to a last minute check that all stakeholders' concerns are covered before significant resources are committed to a particular plan. In other cases, the individual, team, or organization will need to use a story browser whose expanding capabilities are outlined above.

In this paper, we have attempted to do three things. 1. Convince the reader that improving and understanding the ability of individuals, teams, and organizations to innovate more effectively is key to our collective survival. 2. Outline how recent advances in science and technology offer a promise to enhance collaborative innovation. 3. Describe in outline the small contributions along these lines of the IBM Research Knowledge Socialization Group.

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5. Bricks & Bits & Interaction

R. Fruchter

Director of Project Based Learning Laboratory, Civil and Environmental Engineering
Department, Stanford University, Stanford, CA 94305-4020, USA

5.1 Introduction

In today's information technology (IT) and communication intensive environment people, technology and build environment designers, and organizations are challenged to understand the impacts on the workspace, content that is created and shared, and social, behavioral and cognitive aspects of work, play, learning, and community. The study is at the intersection of the design of physical spaces, i.e., *bricks*, rich electronic content such as video, audio, sketching, CAD, i.e., *bits*, and new ways people behave in communicative events using affordances of IT augmented spaces and content, i.e., *interaction*. The study proposes two hypotheses.

Brick & Bits & Interaction Hypothesis: If we understanding the relationship between *bricks*, *bits*, and *interaction* we will be able to

1. design spaces that better afford communicative events,
2. develop collaboration technologies based on natural idioms that best support the activities people perform,
3. engage people in rich communicative experiences that enable them to immerse in their activity and forget about the technology that mediates the interaction.

Change Hypothesis: Any new information and collaboration technology will require change and rethinking of:

1. the design and location of spaces in which people work, learn, and play.
2. the content people create in terms of representation, media, interrelation among the different media, the content's evolution over time so that it provides context and sets it in a social communicative perspective.
3. the interactions among people in terms of the individual's behavior, interaction dynamics, new communication protocols, collaboration processes; relation between people and affordances of the space; and interactivity with the content.

The paper uses scenarios and two collaboration technology examples to discuss the *Bricks & Bits & Interaction* perspective and highlights the behavioral and social changes that have to be acquired as people interact with and in the context of new communication technologies and IT augmented spaces. The two information and collaboration technologies are:

1. MS Netmeeting, a collaboration technology for videoconferencing [1],
2. RECALL™ a research prototype developed at the PBL Lab at Stanford [2].

The two scenarios took place in the context of the education testbed focused on Global Teamwork in Architecture, Engineering, Construction (A/E/C) offered at Stanford University [3]. The A/E/C program engages students from universities worldwide, i.e., Stanford University, UC Berkeley, Georgia Tech, Kansas Univer-

sity, Cal Poly San Luis Obispo, from the US, TU Delft from Netherlands, Bauhaus University from Germany, ETH Zurich and FHA from Switzerland, University of Ljubljana from Slovenia, Aoyama Gakuin Univeristy, Japan, in global teamwork.

5.2 Visibility, Awareness, and Interaction in Videoconference Space

Scenario. Synchronous multi-modal collaboration in a videoconference mediated team meeting between an architecture student at Berkeley and two students at Stanford, a structural engineer and an undergraduate apprentice, is used as a scenario to discuss the method and findings of the study. The study captured the interaction among the three actors by video taping both sites. About 40 hours of interactions were recorded and analyzed using video protocol analysis methods. Two key aspects were studied: the workspace and content aspects present in the process, and the interaction related to the social process and the discourse.

Bricks. From the point of view of *bricks* the study analyzes the affordances and limitations of typical preset physical videoconference workspaces, e.g., labs, or cubicles. More than that the location of the PC and audio/video devices is fixed. In such a videoconference setting one or more participants move, interact, and use the affordance of the technology and the space to communicate with remote team members. The research and pragmatic question is *how can a flexible space be designed to accommodate the changing needs of the interaction, awareness and visibility of the distributed people engaged in the communicative event?*

The analysis focused on the environmental aspects present in the interaction, e.g., the analysis of the participants' movements in the space. From the observations, one important aspect in understanding part of the behavioral patterns of the participants was the study of the workspace used in the interactions. It was reduced to the area surrounding the PC, creating a restricted interaction space. The affordances of the equipments used also determined the way in which the participants used the space. Particularly, two aspects were relevant in the way in which people use the workspace: the locations of the monitor and the video camera.

Both Monitors and Video cameras define preferred locations for participants that narrow the possibilities for using a certain area in the working space. When analyzing the movements of the participants in relation to the location of the equipment, we can see that the movements are restricted to a triangular area, that we have called **Cone of Interaction (COI)**. The Fig. 1 shows the movements of two participants during a real interaction. We identified four major areas in the COI: *Command area (A)* the area in which the person that leads the interaction is located. The position has to do most likely with the use of the input device, and it is all the way around in the case of left-handed users; *Secondary area (B)* is the area occupied by default by the other person or people involved in the interaction; *Pointing devise (p)*, *Microphone area (m)*.

Key aspects have to be considered in relation to the COI. On one hand, the overlapping of functional areas created by the video camera and the monitor. This overlapping creates three zones as shown in Fig. 1: the sector (1) defines the area

in which the user of the computer can have visibility of the screen and be captured by the lens of the video camera; the sector (3) is the area in which no visibility can happen, both for the user of the computer and for the receiver of the image captured by the video camera. However, the sector (2) is potentially most problematic of all, because when being in this area the user of the system can have visibility of the computer screen, but at the same time be out of the camera range without noticing it, creating a visual contact failure in the communicational process.

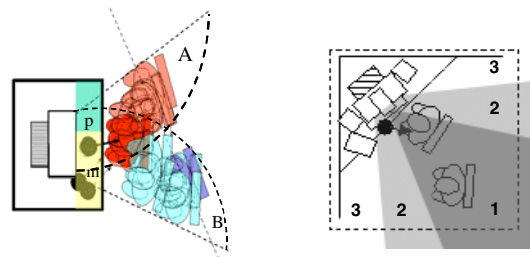


Fig. 1. Cone of Interaction and Areas of Visibility, Awareness, and Interaction

The COI contributes to a false sense of awareness of the participant in the video interaction, by creating the wrong belief that by being in the visibility range of the screen, the actions performed will be transmitted to the non-collocated participant. An example of this wrong sense of awareness is an action that happens often when participants are describing information that involves pointing with their finger at graphical information on the monitor, coined in the study “Faked pointing.” “Faked pointing” can be considered a communication failure situation, because it can lead to misunderstanding and delays in the communicational process. The use of body gestures for conveying the discourse are drastically constrained by the affordances of the video devices in use, and the lack of awareness of this fact by the speaker can lead to important losses in the communicational process.

Bits. During a videoconference meeting, participants manipulate, and edit rich content such as text, 3D models in CAD, and sketches on whiteboards through application sharing. The advantage offered by application sharing provides the participants with interactivity, visibility of ideas and actions in the application, making their thought process visible, as well as manipulation of each other’s content and explore alternatives, i.e. “What if” scenarios.

Interaction. The videoconference technology requires the participants to acquire new communication skills and change their interaction habits to benefit from the multi-modal communication environment. New communication protocol emerge, for instance, since videoconference settings lack the collocated rich queues, e.g., participants spend longer time intervals at the start of the meeting to establish a framework and a rapport. The affordance or limitation of the designed workspace and hardware configuration can lead to miscommunications formalized as communication failures gaze, fake pointing, visibility of all participants and awareness of actions taken in the shared applications in the different situations of space usage by one, two, or more participants.

The video protocol analysis of the 40 hours of interaction captured lead to the identification of patterns of interaction based on the analysis of the verbal and non-verbal discourses. The smallest unit of communication for this level of analysis was the *turn* defined by each intervention produced by any of the speakers in the context of an interaction. The turns were grouped and structured into larger units, conforming three different levels inside the discourse's structure:

1. *Topics*: the topics correspond to those identifiable themes raised by the speakers during the conversation. Different turns can share the same topic.
2. *Episodes*: episodes are series of turns that share some specific functional content in the context of the discourse. These turns in the episode can belong to different kinds of topics.
3. *Protocols*: protocols point out the existence of patterns in the communication between the participants that happen in the inner structure of the Episodes. A protocol is shaped by a particular series of turns, which conform structures of verbal and/or behavioral actions that can be identified as having a particular purpose in the context of the interaction.

In order to evaluate this inner structure of the episodes, two kinds of analysis were applied to the texts. The first one was a technique called linkography [4], which shows graphically the relationship among the different topics present in the discourse. Linkography is useful to identify characteristics of the verbal interaction as the areas enclosed by each Episode, the connections between the Topics, and the recurrence of them. Fig. 2 shows one of the linkography graphics produced. It is possible to identify the recurrence of the topics, represented by several triangles; the bigger the triangle, the farther the appearance of a topic is from the last time it appeared in the interaction. This information was made more explicit by augmenting the linkography method by color-coding the triangles. Use of colors made it possible to identify important characteristics of the topics as the recurrence of them. Those interactions that are more frequent - represented by small series of pyramids - are the topics that constitute the core of the discussion.

The different episodes contained in the interaction were represented in a bar graph in which the horizontal axis represents the temporal duration of the episodes by using proportional scale. This is important to establish ratios between the weights of the different episodes in the context of the whole conversation. This analysis enables the identification of the communication protocols present in the different episodes (Fig. 2). Examples of it are the strips pointed out by the arrows in the graphic, which represent the protocol for producing the transition between episodes. The study then linked the temporal graphic representation of the episodes with the movement of the participants in the videoconference space (Fig. 3) to better understand the affordances and limitations of the bricks and bits during the communicative event and make preliminary recommendations as to how to change and improve the workspace, access to content, and interaction among the participants. In this example, the occurrence of the movements was analyzed in time, correlating it to the verbal interaction, and physical in relation to the computer's location. By crossing the information about episodes and movements in space, the study showed that there is an increment in the physical movements of the participants once a second participant arrives. Nevertheless, the workspace and the hardware configuration do not adapt in a flexible manner to respond to the

change in the number of participants or their location in relation to the hardware. This can potentially lead to limited social interactions and cognitive experiences. The spatial and movement analysis indicated the effect of the location of the video camera in the use of space, i.e., the presence of the camera forces a diagonal disposition of the participants during most of the interaction.

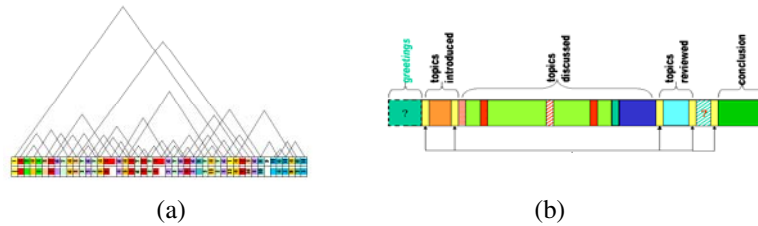


Fig. 2. Meeting Discourse Analysis: (a) Linkographic Representation and (b) Analysis of Temporal Duration of Episodes

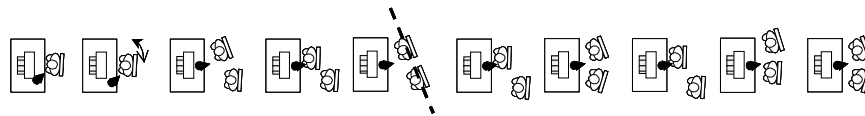


Fig. 3. Movement & Interaction in the Videoconference Workspace

5.3 Mobile Learners in E-learning Spaces

This section turns the attention from the analysis of fixed settings for interaction in which archived knowledge, information, and product models are shared during a communicative event to facilitate teamwork and build common ground, to the needs of mobile learners to capture informal knowledge in diverse formal and informal e-learning spaces. The specific collaboration technology the study focused on was RECALL™ [2]. RECALL™ is a learning and collaboration technology that facilitates transparent and cost effective capture, sharing, and re-use of knowledge. RECALL™ is a drawing Java application that captures knowledge in informal media such as sketches, audio and video.

Scenarios. Two scenarios are offered to discuss the use of RECALL technology and its relation to *bricks & bits & interaction*: *Interactive Lectures* and *Teamwork*.

The questions raised by the *bricks & bits & interaction* perspective are

- How does RECALL™ impact the workspace and the place the interaction activity can take place?
- How does rich content impact the level of retention in the interactive lecture scenario, and the quality of the communication in the teamwork scenario?
- How does RECALL™ change the flow of communicative events?

Bricks. Space design has to take into consideration that brainstorming for new ideas and team interaction do not necessarily have to take place in the office, classroom, or lab, in fact often they take place at the coffee house, airport gateway, etc. The paper identifies the following work and learning spaces:

e-Space (electronic space) – a formal and flexible PBL Lab that supports the diverse activities of mobile learners, such as lecture, presentations, teamwork, individual work. An example of the mobile, wireless, flexible PBL Lab space that is augmented with RECALL™ was built at Stanford. The design of the PBL lab was grounded in cognitive and situative learning theory. The cognitive perspective characterizes learning in terms of growth of conceptual understanding and general strategies of thinking and understanding [5]. The design of the PBL Lab--to provide team interaction with the professor, with industry mentors and team owners--provides a structure for modeling and coaching which scaffolds the learning process, both in the design and construction phases, as well as for techniques such as articulating and reflecting on cognitive processes. The situative perspective shifts the focus of analysis from individual behavior and cognition to larger systems that include individual agents interacting with each other and with other subsystems in the environment [6]. The PBL Lab is built as a flexible learning space that can be reconfigured by faculty or students on an as-needed basis to accommodate the different learning and teaching activities (Fig. 4 a).



Fig. 4. Examples of *e-Space*, *d-Space*, and *g-Space*

d-Space (distributed space) – an informal workspace that supports the mobile learner with wireless connectivity to the instructors, team members, mentors. Fig. 4b illustrates an example of the PBL Lab wireless coffeehouse *d-Space* at Stanford as a social work, and learning space where learners get together and use their mobile laptops augmented with RECALL™, videoconference, and other standard applications used in projects.

g-Space (global space) – a formal and flexible PBL Lab that supports large group interactions in both collocated and global geographically distributed videoconference and RECALL™ connectivity (Fig. 4c).

In such a broad space, i.e., *e-Space*, *d-Space*, and *g-Space*, that provides smooth transitions between formal and informal settings, learning and work occurs anywhere. Consequently, content, knowledge, and people walk with the individual like a virtual knowledge bubble (*k-bubble*).

Bits. The RECALL™ application encodes and synchronizes audio/video and sketch. Production and replay uses a client-server architecture. Once a session is complete, the drawing and video/audio information is automatically indexed and published on a web server that allows distributed and synchronized playback of

the session and from anywhere at anytime. The user is able to navigate through the session by selecting individual drawing elements as an index and jump to the part of interest. The RECALL™ technology invention is currently being patented.

This rich and informal content, i.e., sketch, audio, and video enables the participants to communicate the rationale and context in which their concepts, proposed changes, or questions came up. The interactivity with the content enables users to access the content part of interest and manage information overload.

Interactions. The sketch is a natural mode for designers, instructors, or learners to communicate in highly informal activities such as brainstorming sessions, lectures, or Q&A sessions. Often a sketch itself is merely the vehicle that spawns discussions about a particular design issue. Thus, from a design knowledge capture perspective; capturing both the sketch itself and the discussion that provides the context behind the sketch are important. It is interesting to note that today's state-of-practice neither is captured and knowledge is lost when the whiteboards is erased. RECALL™ act as an exploration environment that captures both an individual memory of ideas and rationale *i-memo*, and team memory *t-memo*.

RECALL™ offers some key benefits for producers and consumers of rich content, such as, zero overhead cost for indexing and publishing on the Web rich content in the form of sketches, audio and video, as well as real-time interactivity. In terms of interaction among team members RECALL™ enables a faster turnover of information and team feedback; instructors can have an insight into learner's thought process beyond the exercise result/answer or question; similar benefits can be observed in play mode or in customer relation management. Since the knowledge is in context, participants can make informed decisions.

5.4 Emerging Changes Influenced by Bricks & Bits & Interaction

Both studies offer insights in terms socio-technical-environmental changes that need to be considered from all three aspects, environmental – *bricks*, technical – *bits*, and social – *interaction*. All three aspects constantly influence each other.

The influence of *bricks* on *bits* indicates that the workspace configuration can enhance or limit the visibility of participants in a multi-modal videoconference and the awareness of shared content displayed on a monitor or screen. Consequently, better software and hardware that supports zooming of the COI would improve the communicative event that has to take place in a fixed and confined workspace. A simple solution that can help improve the visibility and awareness in a video conference setting would be to change the location of the video camera so that there is an overlap of the areas (1) and (2) shown in Fig. 1.

The influence of *bits* on *bricks* leads to changes such as development of flexible structural elements and mobile devices in the workspace that adapt and adjust to address the needs for visualization, composition and manipulation of rich content, or embedded multi-media devices in walls and furniture.

The influence of *bricks* on *interaction* requires participants to change their behavior, acquire new habits as they move and interact in the workspace, as well as

share the workspace to allow awareness and visibility in different scenarios, i.e., individual presence, small or large collocated teams linked to global partners.

The influence of *interaction* on *bricks* leads us to rethinking the design of spaces as adjustable workspaces, e.g., mobile partition walls, flexible furniture, network and power infrastructure that allows connectivity anywhere anytime, to address individual and team work. In addition, *bricks* in the form of formal and informal work, learning, play, and community spaces have to facilitate smooth transitions among *e-Spaces*, *d-Spaces*, and *g-Spaces*.

The influence of *interaction* on *bits* directs our thinking towards the design and development of new software and hardware tools that can for instance resolve visibility communication problems such as “fake pointing” i.e., pointing at information on the screen with hand gestures, “the gaze” i.e., providing eye-contact of remote participants in a videoconference, no matter where they look.

The influence of *bits* on *interaction* requires individuals’ behavior and team dynamics change, as new protocols are formalized and adopted by the participants to best take advantage of emerging collaboration technologies. Social intelligence evolves as participants learn how to share and interactively manipulate rich content, i.e., *bits*. This process enables a globally distributed or collocated project team to build a “common ground” or shared understanding of the goals, constraints, and solution alternatives. The availability of context in which content was created opens new dimensions in the understanding of design decisions. More than that shared rich content impacts the level of retention, attention, and the quality of the communication. Finally, in building new social intelligence individuals learn to share more information in a timely fashion at a faster rate, as well as become responsive to requests for information. This process leads to faster design-build decision iterations and shorter time-to-market solutions in an industry environment, and supposedly a more intense social interaction in any community.

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6. A Distributed Multi-agent System for the Self-Evaluation of Dialogs

Alain Cardon

LIH Le Havre University and LIP6 Paris VI University
Alain.Cardon@lip6.fr

Abstract. We can interpret meaning of the communications between users if we have large ontology on the discourses. We can link these static ontologies with multi-agents systems, and expresses the changes of the multi-agent organizations in a geometrical and dynamic way. So, we can exhibit the meaning of the discourses by emergence in a systemic loop between two agent organizations, and in real time.

Keywords: communication, multi-agent system, emergence, morphology, shared knowledge, meaning.

6.1 Introduction

A communicational system using large networks and involving many users can be seen in two ways. The first is point of view of the exchange of knowledge and of shared knowledge between the users, in a cognitive way. The second is the point of view of the control in and of the system, in a social way. In fact, using networks, users have to communicate and use large kind of knowledge: the exchange of information is always an exchange of knowledge.

With this practice, users make up a new dynamic social space where problems of culture, of power and of social transformations spring up. And the question of the control is inherent in such fields. So, we can have a very deep or a soft control but always we have control expressed by the society itself about the goals of people using networks. Communication is, upper the technical aspect, a social act involved a possible transformation of the social structures. The expression of the control of users in communicational networks is a natural tendency in our societies, for maintain cohesion and avoid breaking. Exchange of information between users is exchange of knowledge and implies the development and the modification of the users' groups. This structure, these organizational modifications must be known for some social and politic structures putting in place the networks and theirs facilities. But these organizational modifications can also be known by users themselves and then tackle a new social space. In this case, the exchanged knowledge is automatically augmented with its interpretation and its social implications.

We present the architecture of such a system allowing the representation of the meaning of communications between users. The architecture strongly uses the multi-agent paradigm.

6.2 System General Architecture

As we generally believe the world to be consistent, we generally expect the same from our representation of it. While the fact we know this isn't true, we usually theoretically consider our abilities to perceive it to be reliable and consistent, and we downplay the possible mistakes we can commit when doing so. For example, classical Communication and Information Systems usually suppose people using it say "the truth", that is that they know what they're saying for sure and don't lie [7]. Communication Systems often don't deal all too well with contradictory knowledge sources, because of the lack of correct information or through malevolence. Another example is the inputs from robot sensors: these sensors aren't perfect and so neither are the data they transmit. These can therefore be contradictory. And we must therefore deal with these contradictions.

Another important characteristic of knowledge in communicational situations is its inherently dynamic nature. When we consider a system that has to help people in their decision making process in a real time framework, what is right at one moment might prove incorrect minutes later [2]. How then can a system cope with such a fluctuating knowledge and in which way it can express the nature and form of the control? It obviously has to keep in mind many possible scenarios, in other words, it has to conceive many possible future worlds in order to match them to recorded plans so that it can efficiently help in the decision making process. However, once the system has chosen some current world representation, it has to retain the other possible representations so as to be able to alter its current state in case the actual situation shifts.

We can focus on the six levels of model of Communication and Information System (CIS) which are the organization levels for complex systems [5]:

1. Physical world, objective entities,
2. Space of development of the entities,
3. Movement, organizations, planning
4. Communication of information
5. Values, symbols, meaning of the phenomenon, intentions,
6. Rules of the social game, power relations, emergence of the global meaning of the phenomenon

The three first levels belong to the field of the classical Information System, the fourth allows the dynamic organization of the three previous. The levels five and six belong to the social, psychological and cultural field. They can not be represented by a-priori defined structures using fixed primal components: the importance and kind of psychological and social categories they represent depend on the current situation itself. They can not be decomposed into fixed components, for the same reason. Like this, these levels belong to a very complex domain. We are interested in these last levels to take into account intentions, opinions and judgments in the communication process, in order to define the good knowledge delivered to the actors.

6.3 Representation of the Semantic of the Communication Act

The approach consists in the knowledge of the situation of communication, of the real and objective facts and also of the mental representations of the situation by actors themselves. So, one includes the factual information and the elaboration of the process of decision, the opinions and judgments of the different actors about the different situations and about themselves. In this approach, the intentionality in the act of information exchange takes precedence over the transmission of neutral information, as in the classical Information Systems.

We use a notion of agent as a software entity [8]. This notion puts agent's notion like an action entity defined at the construction step of a software system and operating in the setting of an open problem to solve. A multi-agent system (MAS) is constituted of a set of agent organizations and is situated in an environment composed of many objects that are not agents that are essentially reactive in a permanent way. This system communicates with its environment by the action of specific agents so-called interfacing agents. The agents of the MAS use objects of their world as well as actions of the other agents to achieve some various actions. They unite their actions to define some collective behaviors. The efficient, visible behavior of MAS will essentially be achieved by the behavior of the agents and will be constructed therefore of distributed manner. This is in the agents, and essentially in the agents that will be distributed the characters of action, the effects the system in whole produces on the environment [1].

We saw in the definition of CIS that the three first levels describe the objective situation. These levels are processed by the communicating information level (so named Level 4). We make the hypothesis that some agents can also represent the levels 5 and 6. These levels constitute a specific domain, expressing evaluated knowledge, subjective, social and cultural aspects about the situation in progress. They are above the four previous ones and alter their structure. This is the first hypothesis of self-reference. They can not be represented, in the system, by functional and static pre-defined categories: each character in these levels, is mainly an *act of communication*. It means, that each communication is wrapped by a lot of agents representing the categories of meaning of the evaluated communication. This set of entities qualifies the communication and modifies physically a part of the structure of the system itself: they are effective software actions.

So we express categories in levels 5 and 6, at the ontological level, with acts of communication [3]. The characterization of the situation according to the different actors is represented by the variability of situations, opinions, judgments, points of view. The representation of this characterization in the system will be a structural modification in space and time, wrapping every communication. The main hypothesis is that plastic model and plastic software structures are well adapted to represent a very evolving phenomenon.

6.4 Semantic Traits and Agents

The only model, which allows such a plastic representation, uses the Multi-Agent Systems: we represent the different characters of the communication by a lot of software agents (c.f. Fig. 1). The sentences exchanged between users are composed of specific words coming from the different ontologies of the discourse domain. Each word or set of words in each message are located in one or more ontologies [6]. We call such a word, or group of words, a *semantic trait*. It expresses a character of the current situation.

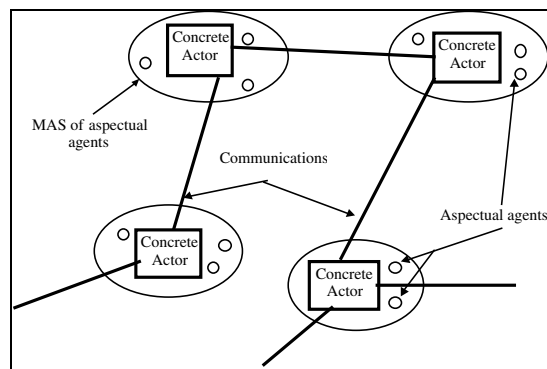


Fig. 1. Software agents wrapping the communicational system.

For each semantic trait, we associate a lot of software agents, the so-called *aspectual agents*. An aspectual agent is a weak agent reifying a semantic trait. For each semantic trait, we can associate several aspectual agents, specifying the semantic trait, its contrary, its opposite, the derived traits ... So, we obtain, for each semantic trait, a lot of aspectual agents that must correspond. For all the semantic traits expressing the whole of ontology of the domain, we have a large set of aspectual agents, that are not independent. The agents are linked by their acquaintances, they can communicate, they can awake or kill others agents, co-operate and form groups expressing complex associations of semantic traits [3].

6.5 Aspectual Agent Organization

Then, for each sentence exchanged between user, we have a lot of semantic traits expressed in a set of activated aspectual agents, the agent that match on the different semantic traits, a group for the sender and another for the recipients. We augment these semantic traits with some subjective aspects about the perception of the situation the users can have, like judgments or feelings like fear, dread, satisfaction, lie ... And we reify these subjective semantic traits with others aspectual agents. These agents awake others in observing aspectual agents and so make emergence of the semantic traits they match (c.f. Fig. 2). Like this, we can express

by agents the six levels of the CIS, including judgments and feeling expressed by users.

The aspectual agents awake or kill others agents, struggle with someone, cooperate with others and form that we call an *agent landscape*, a very dynamic agent organization expressing with augmentation the semantic of each communicated sentence. More than, the aspectual agents take into account the organizational state of the current aspectual organization of each current user receiving a new message. They "set in situation" the current message, taking account of the previous: they constitute an organizational memory.

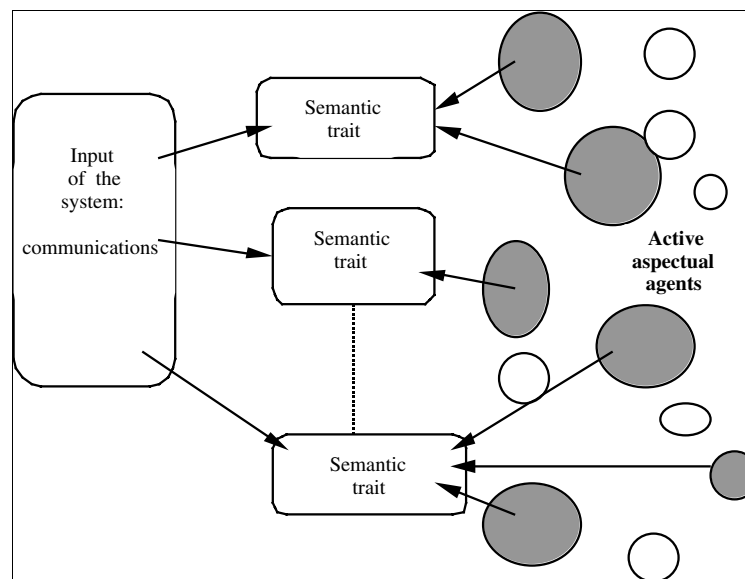


Fig. 2. The aspectual organization operating on the semantic traits

The behavior of these agents, their internal transformation and their communication realize spatial and temporal organization of level 5 and 6. The global characters, which can be found in the multi-agent system, are *emerging characters*. Thus, those agents with their own particular behavior may disturb the organization of the system and make it self-reorganize to exhibit new emerging characters.

In MAS, expected or unexpected structures may appear. We make the hypothesis that emerging structures express the meaning of the communications between users describing them only in a geometrical way we call a *morphology*. This emerging structure represents the accurate views about the different perceptions of the phenomenon elaborated during communication. Because the system is dynamic, the whole emerging structures change according to the evolution of the users' perceived phenomenon. So the agent structure and its evolution reflects the organization and the evolution of the perceived phenomenon itself.

This aspectual organization will grasp the communicational data in order to extract their characteristics. The aspectual agents represent, by their actions, their behavior and inner states, the emergence of semantic traits in account with the proximity with the others previously expressed semantic traits.

6.6 The Emerging Meaning of the Communication: The Morphological Agent Organization

The previously defined aspectual agents allow the expression of the meaning of each semantic trait of the communication in an act of communication. The set of the all MAS wrapped to each concrete actor allows the expression of the whole meaning of the communicational situation. This meaning is generated by *emerging* structures, expressing the morphology of the set of MAS. For this, we have defined the notion of *form of the agent landscape* [4], that is the transformation of the agent landscape in a geometrical way. This is an important point of our work, where we study the coherence and stability of MAS expressing global sense but using geometrical characters of the MAS.

The goal is to build a structural and immediate connection between the set of actors' ideas and the landscape of agents. This notion is central in the model and understood as a real new form of meaning, expressing with a lot of agents the synthesis of particular forms (the aspectual agents) around the different concrete actors.

Given the very great number of aspectual agents, it isn't possible to follow them individually. We therefore study them as a whole, distinguishing shapes and forms in the interactions. We appreciate a form in a geometrical way, using the specific organization of the morphological agents. We call this view of the aspectual agents organization, considered as a population, an *agent landscape* [3], [7]. An agent landscape is space expressing the active aspectual agents, considered as well understandable

In the system an agent landscape is represented by specific projections of the studied agent organization according to height axes. Such a representation defines in fact a new space of dynamic description of any agent organization. The height space dimensions are the following:

- organizational distance: the state of the agent compared with the state of the whole agent organization,
- velocity: the speed with which an aspectual agent has developed so far,
- facility: the ease with which an aspectual agent has developed so far,
- supremacy: a measure of the ratio enemy allied of each aspectual agent,
- complexification: a measurement of the evolution of the inner structure of the agent in us
- intensity of the internal activity: the expression of the exchanges between the inner components of aspectual agent before action,
- persistence: a measurement of the time of life of the agent,
- dependency: the fact the agent is or is not free or dependent.

We express the characters (the dimensions) of this space using specific agents. The morphological agents are the expression of the aggregation of aspectual agents in the landscape made with these agents, according to those height criteria. The set of morphological agent's form a kind of dynamic space, each point in this space is in fact a morphological agent. Such an expression of a massive set of agent is the fundamental result allowing the development of the system.

6.7 Interpretation of the Morphological Organization: The Evocation Agents

The morphological agents provide the stabilized state of the aspectual organization that corresponds to a fixed point of the mirroring process. The reading of the morphology, that is the representation of calculations done by aspectual agent aggregations, provides the emergence of the sense of that has been effectively calculated with the aspectual agent, while taking account of morphological agents of engagement. This notion of emergence has a strictly organizational character well.

But we won't remain at the level of the simple expression of morphological agents in groups. The system must take account of the significance of this morphology, to fear it, would be that to memorize it in an organizational way, that is to take account implicitly in its future activation, in its future engagements. The system has that to be-to-say it functions like an organizational memory.

And another organization of agents, after the aspectual agents and those of morphology be going to take in consideration the state of the landscape of morphological agents to achieve an analysis of its own morphology. It is about representing the sense of the activation of the aspectual agent organization, from its characters of aspect expressed by morphological agents. An organization of agents, the agents of evocation, be going to provide a cognitive view of that that has been expressed by the geometric and semantic information coming from the landscape of morphological agents, above of the aspectual agent landscape.

Agents of evocation, that have a classical structure, are going to represent categories of significance between the action of the robot, the activity of its interfacing agents, the computational development of its behavior and the representation of this development by morphological agents. They express the global consistency of activation while doing choices and decisions of global behavior, while keeping strategies of inhibition of action for certain interfacing, aspectual or morphological agents and while controlling so the general line of organizational emergence achieved in the system.

Let's notice that these strategic actions will be indirect, in relation to every agent's behavior, permitting to constitute a system with emergence of sense with its intrinsic characters of non-stability and learning by structural distortion only. The systemic loop is now closed.

6.8 Conclusion

We have applied such a system for the management of crisis situation in industrial disasters and we have developed a prototype for simulation of communications between actors, coded in Distributed Smalltalk™ [7]. The task at hand was trying to build an understanding of a dynamic, conflicting situation, perceived by the Evaluation System through exchanged messages potentially incoherent or conflicting. To reach this difficult goal, we have proposed architecture for an Evaluation System based on the morphology of the behavior of aspectual agent organizations. We can transpose and apply this model to the dialogs between every virtual user's community. This is a research program where we have to express the ontologies about the exchanged and shared knowledge used by users and adapt the Evaluation System for the case in the environment of each user, above his usual communicational interface.

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7. Public Opinion Channel: A System for Augmenting Social Intelligence of a Community

Tomohiro Fukuhara^{1,3}, Toyoaki Nishida², and Shunsuke Uemura³

¹ Synsophy Project, Communications Research Laboratory, Kyoto 619-0289, Japan

E-mail: tomohi-f@synsophy.go.jp

² School of Engineering, The University of Tokyo, Tokyo 113-8656, Japan

E-mail: nishida@kc.t.u-tokyo.ac.jp

³ Graduate School of Information Science, Nara Institute of Science and Technology, Nara 630-0101, Japan

E-mail: {tomohi-f, uemura}@is.aist-nara.ac.jp

7.1 Introduction

The Internet has become a social place. It allows us to exchange our thoughts and opinions with other people who have similar interests or goals. However, existing communication systems such as e-mail, BBS (Bulletin Board System), chat and instant messaging systems have limitations on eliciting and circulating opinions in a community¹ because of communication costs that block talking various opinions between community members. We consider that social intelligence is a property of a community that enables the members to exchange and evolve their implicit knowledge. To augment social intelligence of a community, facilitating elicitation and circulation of hidden opinions of the members by reducing the communication costs are required.

We have developed the *Public Opinion Channel (POC)* prototype system that reduces the communication costs. POC is a concept of an automatic community broadcasting system[7.1][7.2]. POC elicits and circulates community members' opinions by providing a *story* to the members. A story is a digest of opinions in the community. Although the members have their opinions, they often hesitate to say their opinions to others. By providing the story to the members, they can easily find implicit opinions including not only major but also minor opinions in their community, and are encouraged to say their opinions. The POC prototype system allows members to listen to the stories as radio program, viewing various opinions passively, and send their opinions as anonymous short messages.

¹ community here is a group of peoples who have the same interests and goals, and discussing and working together on the Internet.

Table 7.1. Comparison of costs for receiving, sending, selecting a message between an e-mail system and other communication systems.

	Receiving	Sending	Selection
E-mail (baseline)	—	—	—
BBS	High	Medium	High
Network news	High	Medium	High
Chat system	Low	Low	Low
Instant messaging	Low	Low	Low

7.2 Communication Costs

The communication costs referred to here are expenses of cognitive resources for receiving, sending, and selecting a message by using communication tools on the Internet. There are three kinds of the communication costs: (1) *receiving cost*, which is the cost of a user receiving and comprehending a message by using the communication system, (2) *sending cost*, which is the cost of a user preparing and sending a message, and (3) *selection cost*, which is the cost of a user selecting a message to read.

Table 7.1 compares the communication costs between several communication systems and an e-mail system, such as Eudora² and Outlook³ that receives and sends only a plain text message. A message referred to here is a unit of information such as an article on BBS or from network news, one or several lines of texts for chat systems and instant messaging tools⁴.

BBS and network news incur high costs for receiving and selecting a message. This is because a user has to keep track of messages in order to partake in discussions. When BBS and network news are updated, it becomes difficult to follow discussions. Furthermore, selecting messages from a large number of messages from BBS and network news is difficult.

A chat system and an instant messaging tool require all costs to be low. This is because these systems treat short messages consisting of one or several lines of text. Thus, a user can receive and comprehend the contents of the message easily and instantly. In effect, they can send their thoughts just like talking by using these systems.

From this comparison, a communication system should be designed to meet three requirements: (1) it should allow a user to attend discussions without requiring them to keep track of discussions, and (2) it must help a user to find or select a message they actually wants to read, and (3) it allows a user to send short message.

In addition to these requirements, we added the following to the requirements in order to facilitate community members to acquire stories and

² <http://www.eudora.com/>

³ <http://www.microsoft.com/office/outlook/default.htm>

⁴ including Yahoo Messenger and AOL Instant Messenger



Fig. 7.1. An overview of POC prototype system.

encouraging them to talk their opinions: (4) anonymous messaging, which allows community members to send their opinions without revealing their personal information such as their names, (5) passive viewing of opinions, which enables the members to view opinions without any operations, and (6) continuous broadcasting, in which a POC broadcasts stories at all times by generating new stories or rebroadcasting existing stories.

7.3 POC Prototype System

The POC prototype system consists of a *POC server (community broadcasting server)* and several *POC clients*. Figure 7.1 shows an overview of the POC prototype system. A POC server is a broadcasting system that provides (1) opinions for supporting discussions between community members, and (2) stories for notifying picked out opinions to the members. A POC client is a tool for (1) listening to stories, which are provided as radio program by the POC server, and for (2) exchanging opinions between the members for discussion. In this section, we describe the story broadcasting function of the POC server, and the discussion support function of the POC client.

7.3.1 POC Server

The POC server has two roles: (1) discussion server, which provides opinions to the POC clients for facilitating discussions between community members, and (2) broadcasting server, which generates and broadcasts stories as radio program. We describe the latter function in this subsection.

Table 7.2. Example of a story.

DJ	<i>Next opinion is “affordance”.</i>
Opinion 1	Does anyone know about affordance?
DJ	<i>Related to this opinion, there is another opinion.</i>
Opinion 2	There is a workshop on designing intelligent artifacts. This is a good introduction to affordance.
DJ	<i>This is the last opinion.</i>
Opinion 3	I found a good page on cognitive psychology when I was searching affordance.
DJ	<i>Thanks all. We’re waiting for your opinions.</i>

Generating stories. The POC server generates a story that has a context. Context here means the semantic relationship between sentences. The context is made by linking related opinions and is generated as follows.

1. Pick out an opinion (source opinion) from an opinion database.
2. Retrieve opinions from the opinion database by using title of the first opinion.
3. Sort retrieval results by date order, and first n opinions are added to the source opinion. (n is threshold)

An example of a story is shown in Table 7.2. In this example, a DJ who plays a role of a disc jockey in a radio program introduces three opinions related to “affordance”. These opinions are sorted by date.

Broadcasting stories. The POC server broadcasts stories as radio programs on the Internet. This is done by MP3 audio stream. The POC server generates audio files by using a text-to-speech system (TTS), and broadcasts them via MP3 streaming server. The POC server uses CHATR⁵ for TTS, and icecast⁶ for the MP3 streaming server. A user can listen to the stories via MP3 players such as WinAmp⁷. We regard MP3 players as the POC client for listening to the stories.

7.3.2 POC Client: POCViewer

In this subsection, we describe the discussion support function of the POC client. We have developed an implementation of POC client named *POCViewer* that supports exchanging opinions between community members. With the POCViewer, users can view opinions passively, and compose and send their opinions to the POC discussion server. Figure 7.2 shows an image of the POCViewer. POCViewer shows opinions in the Telop style, i.e., each character of a story appears one by one. The POCViewer has several functions for facilitating the discussions.

⁵ <http://results.atr.co.jp/products.e/frame9.html>

⁶ <http://www.icecast.org/>

⁷ <http://www.winamp.com/>



Fig. 7.2. A screen image of the POCViewer.

Table 7.3. An example of a message.

```

< ?xml version="1.0" encoding="Shift_JIS" ?>
< opinion name="tem_imf" date="2001/5/6 20:52:18"
host="192.168.31.163" reference="comment5.xml">
< title> ATM service in Japan </title>
< comment>
I think ATM services in Japan are inconvenient.
Banks should run their ATMs for 24 hours.
</comment>
< url> http://www.japanese-online.com/language/bank.html</url>
</opinion>

```

Opinion composer. A user can compose, edit, and send their opinion to the POC server. The user can save their opinion as a local opinion, which is stored in the local hard disc, and modify or browser it later.

An example of an opinion is shown in Table 7.3. The opinion consists of a title, a comment, and a reference URL. When the user sends he opinion, she inputs title and comment from the POC client. The POC client inserts XML tags to the opinion, and sends it to the server.

Local mode and network mode. A user can select the mode of the POCViewer as either *local mode* or *network mode*. In local mode, the user can compose and store their opinions into local hard disk. In network mode, the user can not only send their opinion but also view and capture opinions of their community. Local mode is suitable for composing and viewing personal opinions. By separating the local and network modes, the user can store their

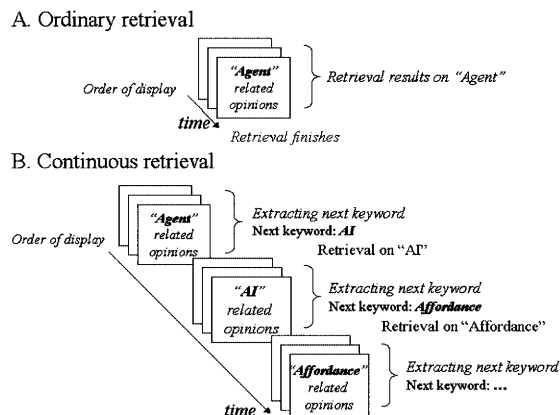


Fig. 7.3. Continuous retrieval. Retrieval is made by extracting keywords from previous retrieval results, and retrieving them continuously.

tentative opinions on their local hard disc, and send the mature opinions to the server.

Capturing opinions. A user can capture opinions on the local hard disk. The user can view captured opinions in local mode. And they can also edit and modify the captured opinions, and send them to a POC server.

Opinion retrieval. A user can retrieve opinions in network mode. The actual retrieval process is run on the POC server. The POC server uses the n -gram search method which searches messages according to pieces of queries consisting of one or two characters[7.3]. This method has the advantage that various texts that include queries partially are retrieved. Thus, the user can view various stories.

Continuous retrieval. A user can view set of similar opinions continuously. The POCViewer can retrieve opinions continuously. When a user retrieves via a keyword, the POCViewer gets another keyword from the retrieval results, and retrieves a set of opinions by using that keyword. Figure 7.3.2 shows an overview of the continuous retrieval.

The user can view a set of opinions based on the retrieval results. In Figure 7.3.2, opinions related to a keyword “Agent” are retrieved. When continuous retrieval mode is off, further retrievals are not perform. When continuous retrieval mode is on, further retrievals based on previous retrieval are performed. The retrievals are performed by extracting a keyword from previous retrieval results. The keyword is picked out according to the feature value of a word. In the implementation, we use the frequency of word as the feature value. Retrievals continues according to previous retrieval results. The user can view another opinions originating from initial keyword given by the user.

7.4 Evaluation

We performed two preliminary experiments of applying the POC prototype system to a practical community. One is a long term observation of opinions in a group[7.4], and the other is a short term observation in a group thinking situation.

The first was on the evaluation of exchanging implicit opinions in a group. This experiment was made for three months. The group consists of eight members, all Japanese, and each member is familiar to the others. 1,329 opinions were collected during this experiment. The members exchanged their opinions about various including not only their business but also movies and TV programs. Some opinions are referring to other members' opinions, and the others are monologues. Although the members post many opinions, we found a point that discussions did not last for a long time. We consider the reason is that the members had got used to the "couch potato" style of viewing of the opinions because the POCViewer shows the opinions automatically. To facilitate discussions in the POCViewer is our future work.

The second was on the evaluation of creativity support by POC[7.5]. Miura argued that POC enabled group members to find an opinion to which they have not paid attention. In this experiment, members discussed on demands or requests from their university using the POC system. The POC server broadcasts opinions in order to provide various viewpoints for the members periodically. In this experiment, circulating opinions enabled members to recognize importance of previous opinions. We will continue evaluation of creativity support by POC.

7.5 Discussion

7.5.1 Automatic Broadcasting System

Tanaka et al. proposed information visualization tools using a TV program metaphor[7.6]. By using these visualization tools, the user can view Web documents or retrieval results from a database in passive viewing style like viewing a TV program.

One of major differences between POC and the information visualization tools is the source of the story. We treat community members' opinions as the source. This is different in story generation method from the visualization tools because identifying minor opinion from major ones is required. In the concept of POC, POC takes up not only major opinions but also minor ones. This requirement is inevitable for fair discussions in a community. Although we have not implemented this function yet, we consider it is important to find minor opinions for the automatic broadcasting system for a community.

7.5.2 POC and Narrative Intelligence

Lawrence et al. proposed to use storytelling to exchange knowledge in a group[7.7]. They argued that there is a function for collecting and sharing knowledge in storytelling. One of points of POC in regard to narrative intelligence is that opinions in the POCViewer become seeds of narratives. In the long term experiment, we found that several opinions becomes the seeds of narratives, i.e., community members replied to the opinions by adding their thoughts or memories related to them. However, what kind of opinions are suitable for seeds of narratives that cause further replies. To analyze this kind of opinions is future work.

7.6 Conclusion

We have developed a POC prototype system for eliciting and circulating opinions in a community. The system augments social intelligence by reducing the communication costs. From the experiments, we found availabilities of the POC prototype system on (1) eliciting and circulating various implicit opinions in a community, and (2) creativity support in a community.

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8. Enabling Public Discourse

Keiichi Nakata

Institute of Environmental Studies, Graduate School of Frontier Sciences, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033 Japan

8.1 Introduction

Increasing concerns for environmental problems have contributed to the general awareness regarding the importance and difficulty of engaging a range of stakeholders in the decision-making process. Those who are involved in making decisions, and affected by the decisions made, from the authorities to the members of public, should be offered an opportunity to engage in informed deliberation, in which views from various perspectives are raised, examined, discussed and taken into consideration before an attempt to reach a consensus is made.

Our ultimate goal is to make such a process of public deliberation, i.e., a “formal or informal process for communication and for raising and collectively considering issues”[1], as effective and meaningful as possible by supporting the community of stakeholders with information tools [2]. This takes into account the increasing cases of initiatives from national and local authorities over the world to make environmental data and information electronically available and the ever-increasing popular access to the Internet, which offer a potential for new knowledge to emerge through interactions of people over the network [3]. In this context, we view “social intelligence” as the potential capability of a community to engage in informed deliberative decision-making process, and the “traces” left behind such a class of cooperative activity.¹

The importance of bringing together the wide spectrum of concerned groups and individuals in realizing a sustainable society cannot be understated. The necessity of partnership between concerned members of the community, such as individual residents, policy makers, industry and NPOs, and the establishment of communication channels for such a collaborative enterprise are repeatedly emphasized [4]. Mere dissemination of information, however it may be designed to cater for the presumed interests of other parties, is not enough: there must be a place for a dialogue based on the information made available.

Such a vision of partnership in social decision-making among various cohorts within a community is, however, not simple to achieve. In reality, there are number of factors that would hamper and prevent its effective implementation. Among them is the difficulty for public to participate in discussions due to the presumed lack of confidence concerning technical issues that might arise. There could be a breakdown in communication due to jargons and technical terminology.

¹ This is by no means meant to be the definition of “social intelligence”, but an example of circumstances under which it would manifest itself.

At the same time, while information concerning public policy could be disseminated, it is not the case the other way around; it is difficult for authorities, to obtain feedback from members of the community, and when they do, that might carry a hostile tone.

We believe that some aspects of the problems raised above can be tackled by providing support for members of the community to have their voices heard more effectively. In our ongoing research, we attempt to address this issue by enabling individuals in informed discussions through the provision of supporting tools aimed to enhance public discourse. Our current research effort is the development of a network-based discussion system that is aimed to support public deliberation on environmental issues [2]. In deliberation, it is assumed that there are both consensual and adversarial processes, since the participatory collective would often include those with opposing agenda and different values. It is not merely a discussion forum; it should be an iterative process in which the overall aim is either or both to reach a consensus (*closure*), and/or to increase participants' understanding of the issues raised and different positions assumed by other participants. Thus, deliberative processes are often seen as essential in making informed, collective decisions. The intended use of the system is primarily for asynchronous discussions in limited domains for which simulation-based analytical tools are available.

The feature that is required in terms of interaction design is the facility for the participants to contribute to the discussion without too much overhead and psychological barriers that hamper the representation of non-technical or novice views. In the past, such a technical divide has often led to the total breakdown of exchange of views between experts and non-experts in the environmental forum, resulting in typical standoff situations between the two antagonistic camps. Instead, in order to promote public deliberation and sharing of the responsibility of collective decision-making by the community, voices should be heard and arguments should be understood.

8.2 Enabling Individuals to Collect and Exchange Information and Opinions

Recent interests in community-oriented (intelligent) information systems projects grouped under labels such as “community computing” and “communityware” highlight the focus on communities with the aim of supporting their formation and their activities. Despite the emphasis on the “community”, we observe that an essential element of these community-oriented systems is the enhancement of interactive capabilities of individual members of a community. This is a natural consequence since the community activities are often decentralized and bottom-up, with the strength being the capability to generate emergent solutions to ill-structured problems for which individual participation is essential.

We see the potential in the community-oriented infrastructure such as Nishida's “Public Opinion Channel” (POC) [5] as a vehicle for increasing social awareness in terms of information exchange and perspective sharing. For such purposes, a conversational interface such as EgoChat [6] can be considered to be a natural

candidate for people to interact through a platform such as POC. In EgoChat, conversations between personal agents are generated and sustained through keyword matching in a conversational database (“conversation base”) that stores conversational fragments (utterances) of the users these agents represent. A human user observes the conversation that unfolds between these agents and can interrupt the conversation and “talk” to the agents thereby increasing the data in the conversation base of his personal agent. The context of the utterance is decided by the topic they (i.e., the user and the agents) are “talking” about.

The significance of such a system is that it uses the everyday form of information exchange in communities, viz. conversations, as the means to elicit information from the human participant. This takes advantage of the nature of human conversation suggested by Schank that humans do not necessarily create new knowledge through conversations but present what they have already thought about, reformulated in the form appropriate for the conversation [7].

Conversation bases held by each personal agent for members of a community together store a rich source of opinions and information held in that community. However, the conversational fragments stored as text loses the non-verbal information such as shared visual information and gestures that are present in ordinary face-to-face conversations. Interactions with such a conversation base should ideally be multi-modal, incorporating visual and audio data to accompany information broadcast. We are currently experimenting the use of wearable devices for information gathering, with the possible effect of grounding information to enable individuals to share with the community what they saw and heard, which would provide a firmer context in which one’s opinions were raised.

Figure 1 illustrates a conversational agent interface modeled after EgoChat, which stages conversations between users’ personal agents. In this demonstrator, an entry in the conversation base contains not only the text of an utterance but also the accompanying visual information at the time it was made, taken through a head-mount camera and stored in a wearable PC, and the gesture information that is captured through a motion capture device with sensors attached the speaker’s arms and interpreted by a simple gesture recognition system. Once uploaded to the conversation server, visual and gesture information is shown in accordance with verbal speech. Our initial experience with the system suggests that, if non-verbal information is seen as the augmentation of verbal information, i.e., as modifiers of keywords, such a multi-modal conversation base is useful when an utterance involves the use of indicatives such as “such” and “like this”, since such information is sometimes not easy to elaborate in words.

While the use of mobile devices may seem rather cumbersome at this point in time, we believe that image capture and transmission would be in the near future as ordinary as voice transmission. Information about the community, such as traffic situation and rising water levels in nearby streams can be collected backed up with images. Using community members and their everyday awareness about the environment offer the possibility of collecting environmental information biased towards concerns of the community members.

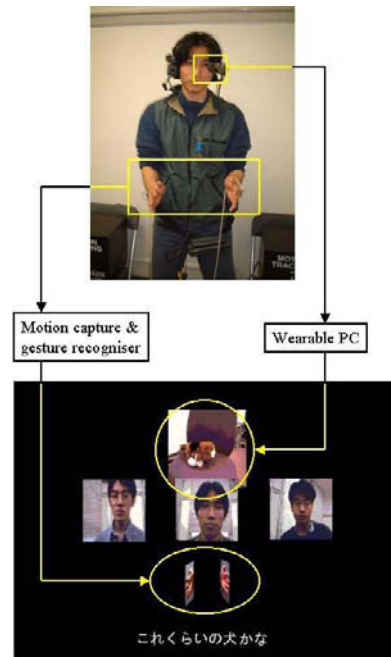


Fig. 1. Providing multi-modal information for the conversation base

8.3 Raising Social Awareness through Position-Oriented Discussions

When a group of concerned individuals share the overall goal of reaching some form of consensus on an issue through deliberation, discussions can be seen as cooperative work. Discussions, however, contain only a weak representation of its common field of work. In other words, the object of cooperation, in this case deliberation and possibly consensus formation, is often poorly represented and not easy for the cooperative ensemble (i.e., the participants) to monitor its progress. Take for example, threaded discussions, which are one of the most common forms of electronic bulletin board systems (BBSs), and incorporated in some groupware applications as the issue-based information systems (IBIS) style of discussion threads. When the discussion is relatively small, a user can easily monitor what is going on by skimming through the contents of contributions. As it grows, unless the user is a very active participant of the discussion, it will not only be difficult for her to monitor the development of argumentation and sub-topics, but also to participate in it. In computer-mediated discussions, the visualization of argumentation addresses this issue, and systems such as Conklin's *gIBIS* [9] have been proposed. In the area of scholarly discourse, collaborative argumentation [8] is

proposed offering hypertext-based solutions. However, neither of these approaches is adequate in dealing with potential problems such as dominance of “loud” voices and effects of inactive but essential participants (“lurkers”), and difficulty in assessing how one is understood by other participants.

8.3.1 Positioning-Oriented Discussion Interface

We address these problems through a form of interaction involving a graphical interface that encourages participants to directly manipulate their positions in the opinion space, thereby visualizing participants’ positions in a discussion. Figure 2 shows an example of the opinion space:

- It describes a two-dimensional space (the “board”) with horizontal and vertical axes representing two of the factors (issues) in the discussion. We believe that ordinary users would not be able to cope with more than two dimensions, especially when it comes to positioning themselves in the opinion space.
- Each participant is assigned an icon, which can be a piece with a designated colour, or her own image such as a photo or cartoon.
- To make a contribution, the user “moves” her piece to the position in the board she thinks that describes her stance in the discussion, and types in the argument or justification for her move. Naturally, she does not have to actually “move”—she can remain in the same position and contribute her opinions.
- In addition to the graphical interface, each contribution is listed in a table, along with information about the contributor, direction of move, and a time stamp.
- Labels of each axis that define the opinion space are changed according to the development of the discussion. Once the labels are changed, the positions are reset to the neutral position (i.e., the origin).

In this way, users can position themselves with respect to their perception of other participants’ positions, revealing how contributions are perceived and interpreted among participants. In our preliminary experiment using this interface, among the comments we received after the session included the clarity of mutual positions concerning issues with respect to relative positions with other participants, and the effect of interface for focusing on issues without diverging too much. Some of the effects of visualizing positions we identified were as follows:

- By “playing back” the changes in the board, the participants were able to recall the flow of discussion and how it unfolded.
- Participants seemed to have retained information as to how other participants changed their opinions.
- By observing the change in opinion, especially at “crossing the axis”, we can analyse what made the participant change their views and its justifications.

Moreover, it provides visual information as to how diverse existing opinions are and how the discussion has contributed to participants closing in (or growing farther apart) on issues being discussed.



Fig. 2. Discussion interface through positioning

When seen as the explicit indication of one's preferences, positioning in the opinion space can be seen as a form of *informal* voting, and the distribution of pieces as the tally of the vote. While taking a formal vote is often avoided for the fear of making premature decisions, taking informal votes is considered to be useful in discussions [10]. Therefore, we expect the advantages (and disadvantages) of taking informal votes during discussions to be inherited in this interaction.

One of the important issues in the position-oriented discussion interface is the choice of labels for each axis. The selection of these labels entails the generation of opinion space, and this in itself is often the point of controversy. To address this problem, a hierarchical issue structure may be created, as an initial road map for the discussion, from which labels for the axes can be selected based on an issue and one of its sub-issues, recording the outcomes as the discussion proceeds.

The discussion system itself is designed to include features such as topic extraction, participant clustering, participation induction, and links to community information. We believe these features would enhance the accessibility to discussions when they grow large. In contrast to the IBIS-family of discussion systems, this interface guarantees the simple snapshot of the state of discussions in terms of opinion space, rather than an ever-expanding list of text or tree.

8.4 Towards “Social Intelligence Design”

The theme of this paper is supporting public to participate in discourse concerning environmental issues for the achievement of a sustainable community. The underlying assumption is that members of the community are motivated and encouraged to do so, but may lack the means and opportunities—hence the development of systems support for enabling public discourse. When we observe the existence of numerous discussion groups and mailing lists in the Internet, it might appear that people already do have the means and opportunity to express their

views and carry out discussions. However, if we are aiming to support deliberative processes for community-based decision-making, we must at the same time consider how a community can be enabled to carry out such a process.

Among the projects that shared the similar aim is RuleNet [11], an experiment in supporting consensus building using an electronic conference commissioned by U.S. Nuclear Research Council (NRC) involving non-technical members of the public on a topic which was until then thought to be highly technical and out of limits to them. Participants' evaluations were reportedly highly positive, primarily because it made them feel that their voices were heard and their contributions had an effect. However, NRC itself questioned the credibility of discussions and the participants' qualifications. There was also a sense of mistrust among some participants towards NRC concerning its motivation, and the technical staff doubted that anything new has been raised. Interestingly, this represents typical stances of parties from different sectors involved in social decision-making—regardless of whether it is conducted with or without electronic conferencing. Therefore it is not the problem of the means, but the capacity of the community to attempt a consensus-oriented decision-making.

What is required is “social intelligence”, as the potential capability of a community to engage in informed deliberative decision-making process. To design social intelligence, then, would be to enable public to engage in discourse. For this purpose, we are attempting to develop means to tap into community information held by individual members, and experimenting on a new form of interaction in carrying out discussions. These two approaches both require the sense of cooperation; in the former, there must be a motivation among members of the community to gather and share information; in the latter, the participants are expected to engage in a constructive deliberative process, and fit into the assumption that deliberation is cooperative work. Ideally, members of the community should be engaged in public discourse as an everyday activity without being conscious of its cooperative nature. One way to achieve it, we believe, is through providing an accessible interface to ease individual interaction, and design of interaction that enhances awareness about the others, fostering reconciliation of differences.

Our current research result is still too premature to judge whether such social intelligence design is possible, and extensive experiments and evaluations are required to draw any concrete conclusions. This will be our focus upon the implementation of prototype systems.

8.5 Concluding Remark

Admitting that visions and projects described in this paper² are rather exploratory and speculative, we believe that fostering public discourse addresses a wide range

² The projects described in this paper are funded by JSPS Grant-in-Aid for Scientific Research and JSPS Research for the Future Program. We acknowledge Akira Kawaguchi and Toshiyasu Murayama who are developing parts of the systems that are referred to in this paper.

of issues in supporting interactions in a community. In the more practical side, we have initiated a pilot project that attempts to develop a system that supports analytic-deliberation by integrating a set of analytical tools into a networked discussion system, including access to simulators that model environmental effects to be used as justifications in the discussion. It is envisioned that approaches described in this paper enhance such a system and contribute to it as enabling technologies for public discourse in achieving environmentally sustainable communities.

It is often said that creation of a sustainable community involves capacity building. We believe that “social intelligence design” is a form of capacity building that enables public to engage in discourse among various value judgments and perspectives, and increase awareness about the environment including its inhabitants and policy makers in order to achieve a rational consensus-based social decision-making.

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9. Internet, Discourses, and Democracy

R. Luehrs¹, T. Malsch¹, and K. Voss²

¹ Technical University of Hamburg-Harburg, Department for Technology Assessment, Schwarzenbergstr. 95, 21071 Hamburg, Germany

² Pixelpark AG, Institute for Media Development, Rotherstr. 8, 10245 Berlin, Germany

9.1 Introduction

It is the very purpose of the DEMOS¹ project – the subject of this paper² – to exploit novel forms of computer mediated communication in order to support democracy on-line ('e-democracy') and to enhance citizen participation in modern societies.

In the following paper we will firstly point out how DEMOS aims to support the democratic process by exploiting the communicative potential of the Internet. Secondly, we will introduce a novel participation methodology which is derived from different social science approaches. Thirdly we will briefly describe the overall design approach.

9.2 Online Support for Democratic Processes

Since the neologism 'e-democracy' refers to both computer mediated communication and democracy without specifying the underlying concepts, there is a need to explain what exactly we mean when using the term. To start with the 'democracy' part of the term, there are different conceptions of democracy and depending on the perspective, different perceptions of how the internet could support, reform or even revolutionise the way democracy works. The most common distinction in the definition of democracy refers to the ways citizens participate in the decision making process and the respective types are called direct or representative democracy. However, these approaches have to be understood not as alternative, opposing systems of democratic governance but as two complementary forms of partici-

¹ DEMOS (Delphi Mediation Online System) is funded as a shared-cost RTD project under the 5th Framework Programme of the European Commission (IST) and is being developed by a research consortium comprising eight organisations from five different European countries, representing the fields of academic research, multimedia, software, market research and public administration. The DEMOS Project (IST-1999-20530) commenced September 2000 and is going on for 30 months. For more information see the project web site: <http://www.demos-project.org>

² This report describes the entire spread of the ongoing project and has to be seen as an short introduction to the particular fields of research and development which are pulled together in DEMOS.

pation which exist side by side in every modern society. It would simply not be feasible in contemporary societies to ask people for their approval before coming to any decisions, like the ancient Greeks did, nor could representative democracy dispense with the civil engagement of the citizens. Mostly, 'e-democracy' in this context calls into question the appropriate mixture of both types of participation, not representative democracy as such. Whether or not more direct participation is perceived as being desirable, depends on the underlying normative model of democracy.

For the liberal, democracy operates by arranging compromises between citizens with different interests on the basis of fair procedures such as equal voting rights. The normative implications are low and the liberties of the citizens are above all defined as 'negative liberties' in the sense of them not being too much directed by the state. From this point of view, more direct participation is only worthwhile – if at all – in terms of plebiscites but not in terms of intensified public debate. In this case e-democracy would only mean substituting paper-based procedures with electronic ones in order to increase convenience and efficiency. By contrast the republican approach to democracy believes that "the formation of the citizen's opinion and will forms the medium through which society constitutes itself as a political whole" (Habermas 1996, 26). Especially in its communitarian reading the republican view tends to over-conceptualise ethical values and the need and chances for ethically integrated societies. Although, here the Internet could be potentially used in its entire diversity in order to support public democratic processes, the expectation that electronic networks will leverage the ethical integration of society seems to be far too idealistic. Though there might be a "trend towards more autonomous local units and the emergence of multicultural and more egalitarian politics, (...) strong counter-tendencies are at work. The Internet is involved in this process by both influencing the desired ends and their opposites" (Sassi 1997, 436).

Instead of identifying democracy merely with voting like liberal democrats tend to or reducing political to ethical questions, like republican democrats are supposed to do, a third variant, the discourse theoretic (deliberative) model, focuses on the *procedures* of public will formation. These procedures are considered to generate legitimacy and practical rationality (Benhabib 1996, 71). "In agreement with republicanism, it gives center stage to the process of political opinion- and will-formation" (Habermas 1996, 27) but without burdening this process with the idealistic expectation of enabling the public sphere itself to act. According to the discourse theory this quality belongs exclusively to the realm of the specialised subsystem called administration. The purpose of the deliberative process is, though, to influence the exercise of power by the administration. "The power available to the administration changes its aggregate condition as soon as it emerges from public use of reasons and communications that do not just monitor the exercise of political power retrospectively, but more or less program it as well" (Habermas 1996, 24). In *this sense*, the project strives to strengthen the legitimacy and rationality of democratic decision making processes by using DEMOS to inspire and guide large scale political debates, to close the distance between political representatives and citizens, experts and laymen.

9.3 A Novel Participation Methodology

The specific communication potential of the Internet can be characterised by the three terms - interactivity, speed and scope. Together, these characteristics allow novel forms of interactive communication between large numbers of participants. On the one hand, it is theoretically possible for an unlimited number of people to discuss a common subject— all ‘talking at the same time’ and contributing to the same discussion. On the other hand, the same participants could also potentially use electronically available information to deepen their knowledge, to give more evidence to their arguments or to convince other participants. Furthermore, people could form coalitions by getting in touch with like-minded people effortlessly or they could group around and discuss certain topics or subtopics of mutual interest. To realise this potential however, there is a need for methodologies that match the media. They need to be able to aggregate and interrelate the individual contributions, to identify and foster the most promising aspects of the discussion, to profile different positions and to strive for convergence between them or at least to figure out what are the truly disputed aspects where no compromise can be achieved. In the latter case, we are always looking for a result from the discussion - whether it is a consensual statement supported by a majority of the participants or what is called a ‘rational dissent’³. Only if the discussion leads to a result is the discussion likely to have any influence on political decision-making procedures. This impact, of course, can be manifold: if the outcome is a clear statement supported by the broad public, it will not be ignored by elected representatives. If the result is merely a widespread collection of different viewpoints, it can serve as input to prospective laws or it can anticipate future objections to planned policies and the like. Taking a closer look at this methodology, we are basically planning to assemble and integrate three well-proven social research methods, namely the Survey technique, the Delphi approach⁴ and the Mediation method⁵. The difficulty here is that these ideas cannot simply be added and compiled to form a new methodology because they are, at least partially, contradictory.

Starting with the classic Survey technique, this method is designed for representative opinion polls and contributes to public opinion formation on a large-scale basis by including (virtually) the entire population. However, this technique is rather unsuitable for interactive participation. Delphi polls, on the other hand, operate with a certain amount of interactive feedback, but this has the consequence of limited scalability. For DEMOS, Delphi polls are extremely interesting because they can be used to exploit expert knowledge. The basic idea is to generate a consensus among a limited number of domain experts by aggregated feedback. Feedback is supplied by the ‘Delphist’ on a strictly anonymous and statistical basis to

³ „A rational dissent (...) implies that, on the basis of what is or has been collectively accepted, the persons involved succeed in understanding precisely what isn’t collectively accepted“ (Miller 1992, 14).

⁴ As an overview see Florian et al. 1999.

⁵ The mediation method is one of the so-called Alternative Dispute Resolution (ADR) procedures, which focus on ‘informal participation’ in the sense that they are not regulated by law. See Susskind and Cruikshank (1989), Maerker and Schmidt-Belz (2000).

exclude direct personal influence among the participants. A Delphi process runs through two (or more) cycles of interview-feedback-interview. After each cycle the experts are asked to rethink their original answers in the light of the statistically aggregated 'group opinion' that has emerged in the previous cycle, until a satisfactory level of convergence or (statistical) consensus is reached.

Whereas both Survey and Delphi are quantitative methods, the Mediation technique is a qualitative method used to reveal problems and resolve conflicts. The basic idea of Mediation is that consensus is not a statistical figure but a negotiated compromise. Mediation is a group process with a limited number of participants, chaired by an impartial mediator, and often running through several cycles of open discussion. It is highly interactive and participative, but being restricted to face-to-face interaction, it is unsuited for large numbers of active participants.

The challenge for the DEMOS project is to take the advantages of all three methods and combine them into a new methodology for on-line democratic participation and interactive conflict resolution. (1) From Surveys it will take the idea of mass opinion polls on a large-scale basis, (2) from Delphi it will take the idea of a cyclical decision process exploiting expert knowledge, and (3) from Mediation it will take the idea of an open process of participative conflict resolution.

The incompatibilities mentioned earlier can be eased by enriching each of the particular methods with elements borrowed from the others. For example, instead of conducting a standardised survey with pre-formulated questions, the items can be generated 'bottom up' by sorting and aggregating qualitative semantic content from earlier or ongoing discussions. The generation of the questionnaire, then, is conceptualised as an interactive process. Like conventional surveys, the main purpose here is to condense and aggregate information and beyond that to summarise the discussion at a certain stage. Accordingly classical Delphi studies can be supplemented with qualitative, open ended questions and extended to involve higher numbers of participants. On the other side, the Mediation method has to be adapted to the specific constraints of the Internet, that is mainly to develop functional equivalents which transfer the method's core strengths, like creating an atmosphere of confidence and trust from face-to-face interactions, to the on-line domain.

The three social research methods (Survey, Delphi and Mediation) will be applied and merged together in the so-called 'DEMOS process'. This process is always concerned with one main topic to be commonly discussed on a limited timeline under the guidance of on-line moderators. To limit the debate to not more than one main topic is a conceptual decision derived from the general objective of the project to concentrate on deliberative discourses with potential impact on public decision making process. It also serves to discourage debates from losing any sense of direction. As a matter of course several processes can be conducted in parallel and each of them will split up into different subtopics during the course of the debate. To focus on just one main topic requires a careful selection of the topic to be discussed on the basis of general criteria. Within our research project we have found that a potential theme should at least meet criteria like popularity, complexity, controversy and persistency. The question of to what extent a DEMOS process affects 'real-world' decisions implies additionally a question relating to the general success of public discourses, which cannot be expanded on here.

The basic process model comprises three different phases each with specific goals. The first phase has above all to initiate, facilitate and broaden the debate and subsequently to identify the most important aspects or subtopics of the chosen subject matter. Therefore the moderators have to analyse and cluster the free text contributions in order to find out the issues most participants seem to be interested in. These tasks will be supported both on a methodological and technological level. The moderators will be backed up by qualitative methods of content analysis and can exploit various mechanisms relating to the social system's self-organisation. A good example of the latter is the detection and use of the thread-generating parts of the discussion. Here a text mining tool will be able to automatically group the text contributions once a set of categories (subtopics) are defined and illustrated by examples.

Additionally, the moderators will have to summarise the discussion during the course of the first phase following a specific procedure. These summaries consist of content and progress related parts and highlight and profile emerging lines of conflict according to the Mediation method. The first phase finally results in a set of proposed subtopics that can be more intensively discussed in separate discussion forums in the next phase. Since this procedure is relying on interpretations of the individual postings as well as of the entire discussion, the result may not exactly meet the preferences of the participants. At this point the Survey method comes into play in order to evaluate whether or not the proposed sub-forums meet the demands of the community and if necessary, to generate ideas on how to revise the list of subtopics.

In the second phase a limited number of sub-forums will be offered by the system on the basis of the poll results. The purpose of this phase is to intensively discuss specific aspects in smaller groups of interested participants, while the main forum still catches those participants who want to discuss the topic on a more general level. Again the moderators will have to summarise the developing debate on a regular basis and at the same time try to tease out and manage emerging conflicts. This is where the Mediation method comes in as part of the moderator's task will be to clarify how and to what extent people are agreeing or disagreeing and at the same time to reduce the distance between diverging positions by deliberative, moderated discourses. The results of the second phase should either be agreement (consent) or a rational dissent in the sense explained above. If required and appropriate, this opinion shaping process can be enriched and supplemented with expert knowledge by conducting Delphi surveys among a predefined set of domain experts. Delphi type studies can either be applied in the original fashion e.g. to reduce the uncertainty with respect to future developments or in order to evaluate certain positions of the community from an expert point of view. Since even experts are often not of the same opinion the Delphi method here provides the participants with a condensed picture of their degree of agreement regarding specific issues. Finally the moderators will close this phase with a summary of what was discussed so far, and will once again ask the participants for their approval (survey).

The third phase reintegrates the sub-forums into the still existing main forum by transferring the summaries and related survey results. Here the participants have the opportunity to see the particular subtopic as part of the general subject matter

and a ‘big picture’ will emerge. Participants have the last chance to comment on the main topic and the assembled results of the sub-forums and the community will be asked to rate the subtopics in terms of importance for the main topic that the DEMOS process was intentionally set up for. The final result will be a condensed document depicting both the results of a dynamic and deliberative discussion and the importance accorded its different aspects in the view of its participants.

9.4 System Design

The design approach for the DEMOS system started with the deduction of the generic DEMOS process from the participation methodology as described in the previous chapter. Accordingly the graphical user interface (GUI) depicts the main characteristics of this process, e.g. visualises the different phases within a given time limit, diverse discussion forums and user roles. The navigational concept is based on a timeline, which allows the user to discern the current phase of the discussion, and the actual topics. Starting from there, users can zoom successively into the focus of their interest, that is, into sub-forums and postings. The number of sub-forums is limited by the demands of screen design and usability.

In order to technically support the DEMOS process, the system architecture consists of four major support components for the modules: Argumentation and Mediation (A&M), Online Delphi Surveys (ODS), Subgroup Formation and Matchmaking (SFM) and Knowledge Management System (KMS).

The main element of DEMOS is the forum, where topics are discussed under the guidance of a moderator. The discussion forums of the Argumentation and Mediation module are provided by the Zeno system (Gordon et al. 2001). Zeno provides particular support to trusted third parties (e.g. the impartial mediator) responsible for moderating the discussions. The Zeno server is a java based application for the www, which enables and facilitates moderated, issue based discussion forums in a secure environment. Zeno discussion forums are integrated with a workspace facility for sharing classified documents.

The Online Delphi Survey module provides the moderators with means to generate and conduct on-line surveys as previously described. In a first step, a discussion will be analysed qualitatively and categorised with the help of a text data mining algorithm based on standard Bayesian inference methods. This engine is able to extract the ‘concepts’, or main ideas out of a free text and to search for ‘similar texts’ based on comparison of these concepts. Once the moderator has clustered the contributions of the users and so preliminary structured the discussion, she may generate a questionnaire and conduct a detailed quantitative survey in order to validate her findings, clarify particular issues or focus on certain aspects. Furthermore the ODS component supports Delphi surveys and the visualisation of results, which are subsequently used to further organise the DEMOS process and also to establish new forums and groups of users.

The clustering of users is crucial for the scalability of the system. It will be handled by the Subgroup Formation and Matchmaking module which makes use of

different profiling information. To maintain scalability on the technical level, SFM is also based on the categorisation tool. The first, limited deployment of the system will lead to a deeper understanding of the users behaviour in the DEMOS environment. Once, the behaviour of users and the rules are known precisely, further tasks can be automated. It is planned to represent users as well as forums with software agents. These agents will carry a set of rules derived from the first, 'manual' deployment of DEMOS, which will allow forum agents to match like-minded users and experts, user agents to identify appropriate forums and users to set up their own groups and forums inline with the progress of the main process. In other words more and denser interaction between a large number of participants can be realized by the help of software agents in the context of DEMOS than in any real world environment. This can be labeled as 'interactive mass communication', which denotes a new interaction type owing to the diffusion of the web. Before, it was just part of the definition of mass media, that interaction between sender and receiver was inhibited by interposed technology (Luhmann 2000). As new means of communication and interaction induce new and unexpected forms of behavior, we furthermore expect to observe emergent structures in this 'hybrid society' which may be also of interest for basic research problems like the so-called 'micro-macro-link'. This problem is of crucial importance for both sociology and computer science⁶ and is especially focussed in the recently established research field 'socionics' (Mueller et. al 1998, Malsch 1998).

The agent's ability to learn will be finally used for the Knowledge Management System (KMS). As described above the categorisation engine will enable agents to search for 'similar texts' based on comparison of extracted concepts. In particular, this allows agents to find documents, even if they do not contain a desired keyword. The agents can then be used to represent a particular set of documents covering a certain subject matter. Providing the participants with a couple of initially trained agents, the users can further modify their personal copies by retraining. Furthermore, the agents can be shared among the users, so that participants will not have to start their own research from scratch, but can retrain an existing agent and so reuse the expertise of others⁷. With the anonymous exchange of agents bound to a certain topic, even users with contradictory theories or opinions can mutually benefit from their respective research by using foreign agents. Even if the agents are not perfectly trained with respect to the information needs of particular users, it may at least set them on a new track. The main idea is to enable "communication through shared knowledge" (e.g. exchange agents), which was one of the initial ideas of Tim Berners-Lee (1997) when developing the world wide web.

⁶ E.g. in the field of 'Distributed Artificial Intelligence' (Gasser 1991)

⁷ This concept has initially been developed in the project www.estonia-sinking.org (funded by the Media II program of the EC), where users and groups with different (even contradictory) interests and prior knowledge can conduct their research about the reasons for the sinking of the ferry Estonia.

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10. How to Evaluate Social Intelligence Design

Nobuhiko Fujihara

Naruto University of Education / Synsophy Project, CRL
Takashima, Naruto, 772-8502, JAPAN
email: fujihara@naruto-u.ac.jp

In this paper, it is discussed how to estimate computer network tools which support communications among community members. So far, standard methods do not seem to be developed enough to evaluate tools appropriately. How we should evaluate network communication tools designed to support social intelligence and to facilitate knowledge creation in a community? I'll propose some important points which should be taken into account to estimate tools, and discuss some methods of evaluations through the introduction of our trials to estimate the effect of Public Opinion Channel (POC) on knowledge creation[10.1, 10.2, 10.7].

10.1 Computer Networked Community as Social Intelligence

First of all, in order to discuss social intelligence design, I propose a viewpoint that considers societies and communities (especially computer networked communities) as having a kind of intellectual existence. The viewpoint would enable us to apply some useful research interests, theories and methodologies from studies of human intelligence to the discussion. It allows us to define the terms social intelligence and social intelligence design as follows¹. *Social intelligence* (SI) is defined as an ability which communities have to solve various problems. *Social intelligence design* is defined as the design of mechanisms of communities which are related to intellectual activities by the communities and their members. For instance, a design of SI means to arrange channels of information to facilitate knowledge creation by communities and their members.

The viewpoint mentioned above generate new research interests on SI as follows:

- Do SI develop? Does the development of SI relate to the development of communities?
- What type of network communication systems do SI support?

¹ Some researchers may define the term *social intelligence* as an ability to get along with others, or as the objects which have such kind of an ability[10.6]. Of course, it is very important to discuss how design this kind of objects. But in this paper, I don't use the term SI in this manner.

- Can SI be divided into subcategories? Can we apply the distinctions used in psychology, for example, *fluid* intelligence and *crystallized* intelligence?
- Can SI quotient (SIQ) be measured? Can we create SIQ measurement tests?

It is worth dealing with each of these issues, and there are further research issues also to be considered. In this paper, I focus on just one of these issues. That is, I'll discuss how to evaluate a social intelligence design — in concrete, how the development of SI is measured when a community adopts a new network communication tool.

In following sections, I emphasize here these three points. First, to evaluate tools, a baseline, “control” condition should be set up appropriately. The effects of tools can be measured by comparing the case in which tools are used and a baseline condition. Second, to evaluate tools, some different types of methods should be used together. Especially, researchers do never evaluate tools only based on users' subjective judgments obtained by questionnaires, estimations, and introspections. Third, I'll discuss the possibility to apply the network analysis to investigate how community members interact to each other and how knowledge creation is facilitated.

10.2 The Importance of Control Condition in Evaluating Social Intelligence Design

Various types of network communication tools have been proposed. Some of these tools aim to support knowledge creation, and some aim to support communication among community members. If tools achieve their goals, their mechanisms would apply to developments of new tools. On the other hand, if the tools don't achieve their goals, they should be improved. To estimate whether tools attain their functions, the differences should compare performance of a community or community members between the case in which tools with the function are used and when tools without the function are used. The case in which members use tools without the function is called as *control condition*. When control condition is biased, the effect of the function devised on tools cannot be estimated exactly. Thus, it is very important for the estimation of the tool's effectiveness that control conditions are set up appropriately. Furthermore, when control condition is not set up, it could not be denied the possibility that a community and community members achieve performances even if without the tools. But in some researches, tools seem to be estimated without setting a control condition. It's not enough to decide whether the tools really support activities of a community and community members.

How should a control condition be set up? One of the appropriate methods is that tools are designed as a composition of a basic part and some additional parts. The case in which people use a tool constructed with only a

basic part may constitute a control condition, and the cases where people use tools constructed with a basic part and some additional parts may constitute experimental conditions. The effect of a tool would be observed as the difference between the control condition and the experimental conditions. For example, Public Opinion Channel (POC) which is developed and researched by my colleagues and me, is designed in such a way[10.1, 10.2, 10.7]. POC is an interactive community broadcasting system. POC collects information from community members, edits and summarized information, and broadcasts it as a story. Community members listen to a story, and respond to it. Repeating the cycle, POC creates continuous information circulation in a community. To estimate the functions of POC, the case where the system is used which has only basic functions, that is, collecting messages and broadcasting them, is set up as a control condition. Research issues on POC are “How should information be summarized to facilitate knowledge creation in a community?”, “Are anonymous communication systems effective to inhibit troubles in communication like flames?”, and so on. The cases can be used as *experimental conditions* where POC with additional functions reflecting these issues is used. One of possible experimental conditions would be a POC with a summarization function. The effect of the summarization function could be observed when comparing the differences of some measurements, for example, quantities of message circulation, and the increasing rate of users, between the control condition and the experimental condition. In a similar way, some modules which aim to implement the same function can be compared.

Tools are not always designed with modules. As another way to set up a control condition, typical situations can be used where people use ordinal network communication systems like mailing lists, bulletin board systems, and chats. For the purpose, it is useful to define typical situations and to standardize procedures to collect data and to analyze data. Fujihara and Miura observed search engine users who query information from WWW and analyzed their behavior[10.4, 10.5]. In the research, they proposed categories to describe information query behaviors from WWW with search engines. Such research would reveal our common activities in network communities. It will give us a baseline to estimate novel network communication tools.

10.3 How to Evaluate POC

Methodologies to estimate whether network communication tools facilitate knowledge creation could be classified into following three categories:

- analyses of users’ subjective estimations and introspection collected through questionnaire
- log analyses of users’ behavior in natural conditions
- experimental methods

Analysis of users' subjective estimations and introspection is a very effective method because it is easy to operate and it gives us rich information on users' thoughts directly. On the other hand, the data can be easily biased by subjection of users and experimenters. Some researchers reported that users do not always recognize their own behavior exactly and their subjective judgment and behavior sometimes are divided[10.8, 10.9]. Log analyses and experimental methods supplement such a methodological problem because they give us information users' behaviors. But, of course, these methods have some problems. It is difficult to operate, and show us only a small part of facts on usage of tools. In order to estimate network communication tools, it is necessary to use these three methods together.

Now, my colleagues and I estimates POC with these three methods. Among these estimations, I'll focus on the result of log analysis. It is because we are trying to develop the method for analyzing network communication tools and knowledge creation generating on network communications, that is, the application of the method called *network analysis*[10.10].

Network analysis is the method to analyze relationships among community members and relationships among companies. It is mainly used in the field of sociology. It describes networks as graph structure (Figure 10.1). Each

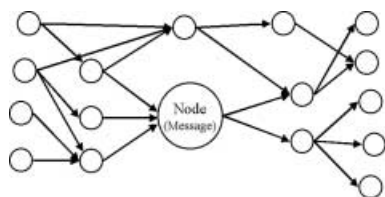


Fig. 10.1. Graph structure of network analysis.

node described as circle means a person or a company, and each link means the relation between people or companies. It is used to investigate the structures of networks, the effect of network structures on community members, and its mechanisms. Some methods for quantification are proposed. One of the representative quantification methods is *degree*. Degree means the numbers of links each node has. Especially, links which come into each node are called *in-degree*, and links which go out from each node are called *out-degree*. In this case in-degree is 3 and out-degree is 2.

With considering each message sent to POC as node, I described a network. According to the ways how to link nodes, there are some possibilities to describe a network. For example, one message and a message replied to it can be linked to describe a network, and messages sharing same topics can be linked. Here, I adopted the latter way, that is, messages sharing two or more content words (almost of which were nouns) were linked. Among all messages (about 1530 messages), first 100 messages were used to make a graph structure (Figure 10.2). In the usual network analysis, each node repre-

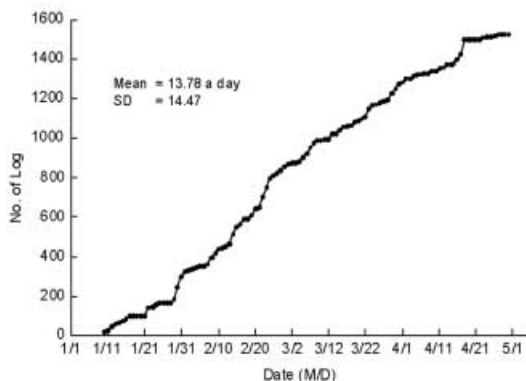


Fig. 10.2. Progress of number of logs collected into POC

sents each person or each company. But in this analysis, each node represents each message. This may be characteristic of our analysis, that is, analysis of knowledge creation².

Figure 10.3 shows the network structure based on 100 of POC messages. Each square represents each message, and the numbers written in squares represent ID numbers of messages. Smaller the ID number is, earlier the corresponding message were sent to POC. Twenty nodes had no links to other messages (e.g., nodes 2, 7, 20), and some constructed very simple links (e.g., links of nodes 69 → 70, 33 → 40 → 44). Sixty-five messages constructed highly complex network. It is found that some nodes have many links and play cores, central roles in the network (e.g., nodes 53, 82, 97). Other nodes have only a few links and play peripheral roles in the network (e.g., nodes 5, 10, 99). The centrality of nodes can be quantified by degrees. Figure 10.4 shows degrees, in-degrees, and out-degrees for nodes.

The average of degrees was about 9. On POC, members would communicate on multiple topics in a time. Probably this would lead smaller size of the average of degree. Other media, like BBS, people tend to debate one fixed theme. It is expected that messages have a tendency to share more words and the average of degrees is larger.

Out-degree decreased as the function of ID number, and in-degree increased. It was probabilistically reasonable. But some messages had larger degrees than this trend. Probably, we could regard such shifted messages as an index of the centrality. Five messages had in-degrees larger than the average plus 2 standard deviations and six messages had out-degrees larger than the average plus 2 standard deviations. These were larger than probabilistically calculated values (2.3) if messages were linked according to normal distribu-

² There are only a few of researches which use a network analysis to describe knowledge representation. For example, Ferstl and Kintch described knowledge representations which people made when reading texts[10.3].

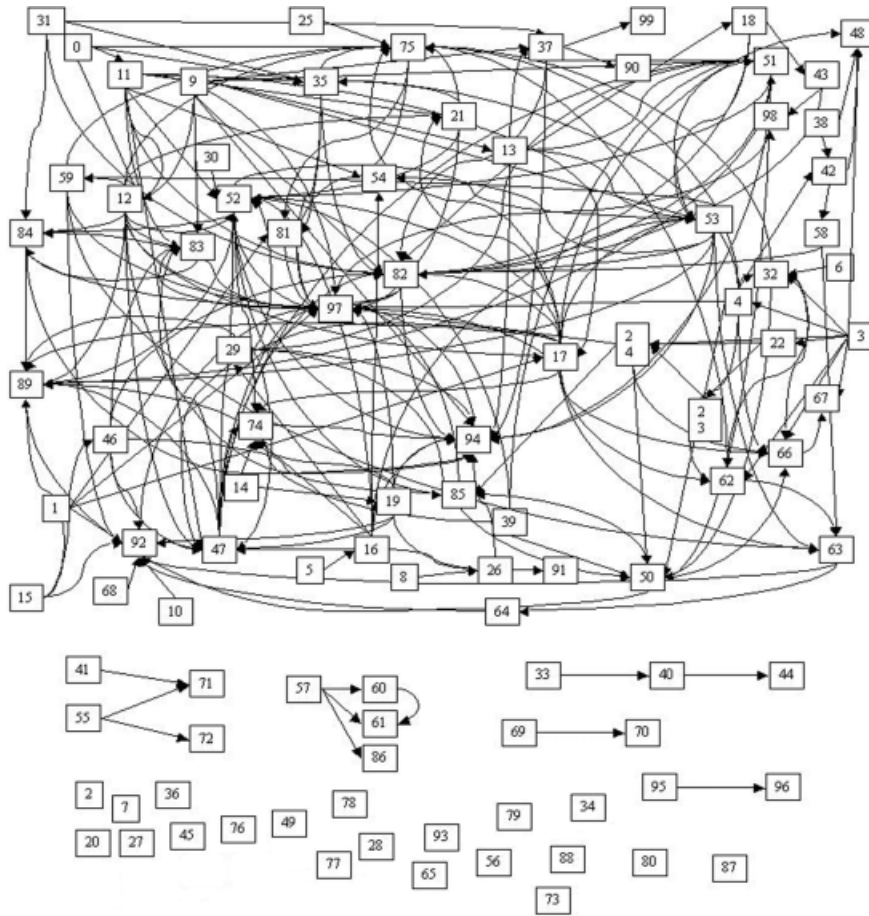


Fig. 10.3. Network analysis of POC

tion. These central nodes have opportunities to connect with themes which are originally unrelated to each other. It could be considered the number of such nodes reflects how tools facilitate knowledge creation in a network community. If so, POC would be regarded as an effective tool to support intelligence.

10.4 Future Works

The analyses mentioned above were just a first step of our trials. So, we have a lot of issues to discuss as future works. It is necessary to compare the result with results of network analysis of other media like BBS. As POC

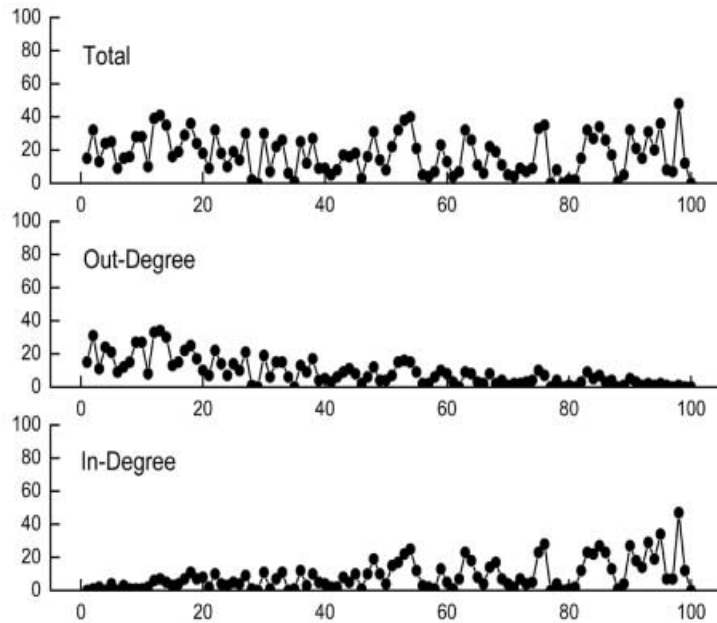


Fig. 10.4. Degrees, in-degrees, and out-degrees for nodes.

is developing, results of network analysis of POC with additional functions should be compared with the results mentioned above, that is, POC with only basic function.

Based on the network, there are other possible ways to investigate whether the system facilitate our knowledge creation. For example, based on the degrees messages could be classified into some clusters. If there were links which connected messages from different clusters, that may indicate the system facilitate our knowledge creation. Also, the numbers of links which connected chronologically separated messages may be one index of knowledge creation. But the network analysis would give us an interesting viewpoint to evaluate network communication tools. We have to elaborate to the method of applying the network analysis. It is expected that the analysis is an effective way to evaluate network communication tools and to investigate our knowledge creation.

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11. Overview

Akira Namatame

AESCS-2001

The first international workshop on Agent-based Approaches in Economic and Social Complex Systems (AESCS) was initiated as a result of the growing recognition of the importance of the computational approaches to study complex economic and social phenomena. The fundamental objective of AESCS 2001 was to foster the formation of an active multi-disciplinary community on multi-agents, computational economics, social dynamics, and complex systems. The aim of AESCS 2001 was also to bring together researchers and practitioners from diverse fields, such as computer science, economics, physics, sociology, psychology, and complex theory for understanding emergent phenomena or collective behavior in economic and social systems. We also discussed on effectiveness and limitations of computational models and methods in social sciences. This workshop also intended to increase the awareness of researchers in many fields with sharing the common view that many problems economic and social systems will require collective information-processing with a large collection of autonomous and heterogeneous agents.

The technical issues to be investigated include the followings:

1. Formal Theories on Agent-based Approaches
 - agent-based computational foundations
 - theories on rationality, intention, emotion, social action, social interaction
 - heterogeneity and diversity of agents
2. Computational Economics and Organization
 - agent-based economics
 - market-based computing
 - artificial markets
 - agents in financial engineering
 - econophysics
 - computational organization theory
3. Formal Theories of Social Dynamics
 - methodologies of modeling social behaviors
 - chaotic and fractal dynamics
 - dynamics of populations
4. Collective Intelligence
 - collective decision and behaviors
 - emergent intelligence

- social intelligence

5. Related Areas

- evolutionary economics
- complex theory
- evolutionary computation
- evolutionary games

We could solicit many high quality papers which reflect the result of the growing recognition of the importance of the areas. All papers have receive a careful and supportive review, and we selected 13 papers out of 27 for the proceedings. We hope that as a result of reading the proceedings you will share with us the intellectual excitement and interest in this emerging discipline. Finally, we would like to acknowledge the support and encouragement of many peoples in helping us getting this new conference started.

General Chair

Akira Namatame

National Defence Academy, Japan (nama@nda.ac.jp)

Program Committee:

Yuji Aruka

Chuo University, Japan (aruka@tamacc.chuo-u.ac.jp)

Kathleen Carley

Carnegie Mellon University, USA (carley+@andrew.cmu.edu)

Shu-Heng Chen

National Chengchi University, Taiwan (chchen@nccu.edu.tw)

Sung-Bae Cho

Yonsei University, Korea (sbcho@csai.yonsei.ac.kr)

Hiroshi Deguchi

Kyoto University (deguchi@econ.kyoto-u.ac.jp)

Hitoshi Iba

University of Tokyo, Japan (iba@miv.t.u-tokyo.ac.jp)

Kiyoshi Izumi

Electrotechnical Laboratory, Japan (kiyoshi@etl.go.jp)

Masao Kubo

National Defence Academy, Japan (masaok@nda.ac.jp)

Koichi Kurumatani

Electrotechnical Laboratory, Japan (kurumatani@etl.go.jp)

Thomas Lux

Kiel University, Germany (lux@bwl.uni-kiel.de)

Hideyuki Mizuta

IBM Tokyo Research Laboratory, Japan (E28193@jp.ibm.com)

Azuma Ohuchi

Hokkaido University, Japan (ohuchi@complex.eng.hokudai.ac.jp)

Hiroshi Sato

National Defence Academy, Japan (hsato@nda.ac.jp)

Keiji Suzuki

Future University-Hakodate (suzukj@fun.ac.jp)

Keiki Takadama

ATR, Japan (keiki@isd.atr.co.jp)

Hideki Takayasu

Sony Computer Science Laboratory, Japan (takayasu@csl.sony.co.jp)

Takao Terano

University of Tsukuba, Japan (terano@gssm.otsuka.tsukuba.ac.jp)

David Wing Kay Yeung

Hong Kong Baptist University, China (wkyeung@hkbu.edu.hk)

12. Analyzing Norm Emergence in Communal Sharing via Agent-Based Simulation

Setsuya Kurahashi and Takao Terano

University of Tsukuba, Otsuka 3-29-1, Bunkyo-ku, Tokyo 113-0012, Japan

This paper describes an agent-based simulation study on the emergence of norms on information communal sharing. To carry out the study, we utilize our simulator TRURL, which (1) contains software agents with decision making and communication functions, and (2) has the capability to evolve artificial societies with specific characteristics defined by a given objective function to be optimized by genetic algorithms. Unlike the literature in social psychology research, which mainly applies evolutionary game theory to homogeneous agents for the simulation, TRURL focuses on the decision making behaviors of heterogeneous agents. Our experimental results have suggested that, contrary to the results of social psychology study so far, for information oriented properties, free riders in the society will not collapse the norm of communal sharing of the properties.

12.1 Introduction

A norm in a society generally means expected behaviors of the members, decision criteria of the members, and/or the evaluation criteria that the society expects. Norm constitutes social pressures to conform people in a group. There are various levels and forms among public and private norms. Examples of such norms are (1) customs resulting from daily repeated behaviors, (2) morality as criteria of right and wrong, and (3) the law as public forces.

In this paper, we will focus on a communal sharing norm. By the communal sharing norm, we mean that people share their resources together. Such sharing of resources plays an important role as a reciprocal norm in human behaviors. Communal sharing encourages us to maintain human relations and closeness [12.1]. The resources for communal sharing include money, physical properties, services, love, social approval, and information [12.2]. Recent rapid development of the Internet has widely changed our society characterized by information networks. Based on the viewpoint, this paper analyzes the birth, growth, and stability of communal sharing of information resources in a society.

To carry out the study, we adopt an agent-based simulation model. Agent-based models can usually find macro phenomena from the interactions among agents. Although a model designer knows functions and natures of agents, (s)he doesn't know what phenomena would happen as a whole during the simulation. Contrary, in the following aspects, our agent-based model is different from conventional macro models to analyze social phenomena. Our

approach is characterized by the facts that: (1) the simulation model consists of heterogeneous agents, which have functions of decision-making and communication; (2) we observe emergence of social phenomena as a result of optimization of a social macro index by genetic algorithms; and (3) we analyze the emergent phenomena and characteristics of each agent.

This paper is organized as follows: We first discuss several existing norm studies so far. Then, we briefly describe our simulator TRURL and apply it to the analysis on the communal sharing norm. Finally, we state the effectiveness of our agent-based simulation model.

12.2 Related Work on Studies of Norms

Norms include personal norms and group norms. They can prevent someone from doing deviant behaviors through rewards and punishments in order to reduce tensions in a group. Norms urge people to conform to common judgments and behavioral patterns. Norms are predominant means to control a society and/or firms. We classify studies of norms into the following areas.

Economic institution analysis. Economic institution analysis usually utilizes evolutionary game theory. Researchers on the area have discussed the emergence and stability of diverse economic institutions [12.3, 12.4, 12.5]. Their basic technique, evolutionary game theory analyzes economic institutions based on the concept of Evolutionary Stable Strategy (ESS). Using the concepts, they have described the stability of economic institutions, the path dependency, and the complementarities of institutions. Aoki[12.6] has found two institutions of corporation systems as equilibrium points of the evolutionary game. Their approach is applicable to analyze the emergence and stability of economic institutes about norms, however, they do not consider dynamic interactions among agents nor mutual understanding about agents' inside models.

Social network. In social network research, graph theory is often used. A center of an organization and a hidden relation among members are discussed using graph theoretic mathematical models [12.7]. In a network structure and a protocol analysis of electronic communities, socio-metric measures such as a degree of leadership existence have been proposed. They show birth, growth and maturity of norms in electronic communities.

Social psychology and cognitive science. In social psychology, norms of human behaviors have been investigated with various data of psychological experiments. Processes to form norms have been analyzed experimentally in terms of leadership [12.8], the effects of group pressure [12.9], and the influence of a consistent minority [12.10].

Intolerant members who show an attitude of refusing resource sharing are critical barriers for the free riders. The experimental results have shown that

those intolerant members are able to inhibit the emergence of the free riders. In summary, they have reported that (1) Intolerance is a stability condition of a norm, and (2) As a result that people choose adaptive behavior at a micro level, a communal sharing norm emerges at a macro level. These researches [12.11] [12.12] show us new viewpoints about group human behaviors that there is an evolutionary process to adapt to an environment for a basis of forming a norm.

12.3 Artificial Society Model TRURL

The roles of computer simulations in organization theory have been re-evaluated in social science literature. However, many of the approaches seem to report too artificial results. To overcome such problems, we have developed a novel multi-agent-based simulation environment TRURL for social interaction analysis.

- The agents in the model have detailed characteristics with enough parameters to simulate real world decision making problems.
- Instead of manually changing the parameters of the agents, we evolve the multi-agent worlds using GA-based techniques.
- Each agent exchanges knowledge and solves its own multi-attribute decision problems by interacting with the other agents

12.3.1 Agent Architecture

Roughly, an agent in TRURL has event-action rules. Each agent exchanges knowledge and solves its own multi-attribute decision problems by interacting with the other agents. Predetermined parameters define the agents' congenital characteristics. The parameters are not changed during one simulation, but are tuned by GA operations when the world evolves.

$$\mathbf{P}_p = (\mathbf{c}_p, p_s, p_r, p_a, p_c, n, \alpha, \beta, \gamma, \delta, \mu),$$

where, \mathbf{p}_p is gene sequences, \mathbf{c}_p is physical coordinates, p_s is probability of message sending, p_r is probability of message reading, p_a is probability of replying attitudes for pros-and-cons, p_c is probability of replying attitudes for comment adding, δ is metabolic rate, μ is mutation rate of knowledge attribute values, α , β , and γ are parameters, and n is the number of knowledge attributes the agent has.

These parameters represent characters of agents.

The agent usually has some subset of knowledge only which the agent can use for decision-making. The knowledge the agent has is a set of knowledge attributes, which is defined as: $Kd = \{N, W, E, C\}$, where N is name of the knowledge attribute, W is importance weight of the attribute, E is evaluation value of the attribute; and C is credibility weight of the attributes.

12.3.2 Communication and Action Energy

A communication process can be considered as a decision-making process on the basis of conformity behavior. In this model, we define some parameters of knowledge attributes, which change when an agent receives a message. We show those definitions of parameters, which are weight w , evaluation e , and credibility c . As the result, knowledge of a high credible agent may affect a low credible agent. When both agents have the same tendency about some knowledge, their credibility increases each other.

$$\begin{aligned}\Delta w_{kd}^i &= \sum_{j \in S} \alpha (w_{kd}^j - w_{kd}^i) \cdot \max(0, c_{kd}^j - c_{kd}^i) \\ \Delta e_{kd}^i &= \sum_{j \in S} \beta (e_{kd}^j - e_{kd}^i) \cdot \max(0, c_{kd}^j - c_{kd}^i) \\ \Delta c_{kd}^i &= \sum_{j \in S} \gamma ((1 - 2 \cdot |e_{kd}^j - e_{kd}^i|) \cdot \max(0, c_{kd}^j - c_{kd}^i))\end{aligned}$$

$w_{kd}^i, e_{kd}^i, c_{kd}^i$ are weight, evaluation, credibility of $agent_i$'s knowledge attributes kd , α, β, γ are transfer ratio, S is a set of *agents* who send messages to $agent_i$ in period t .

Action energy m , which is an acquired parameter increases in proportion to the amount of information that the agent has gotten. m is initialized in a random order by normal probability distribution. It decreases by metabolism δ when the agent send information to the other agent. On the other hand, if the agent receives valuable information from the other agent, it increases. It regularly decreases while it does not communicate others.

12.3.3 Inverse Simulation

In a regular simulation method, we get results successively while the parameters are adjusted. The inverse simulation of TRURL gives an objective function at the beginning, then searches for parameters evolutionarily. We don't adjust them intentionally. Accordingly we can know what nature or character of agents creates the organizational structure of the society after communication.

Artificial society TRURL generates many societies with genetic algorithms, then it can recreate a similar society in terms of a social macro index. Each society is represented as genes of predetermined parameters of agents who constitute those societies. Those societies are evaluated with a social macro index after interactions among agents. Selection, crossover, mutation and reproduction are repeatedly carried out. The social architecture is gradually organized by a social index as an objective function.

Social network researches have shown that the process of communication and opinion formation in a community can be measured with a socio-metric. If this socio-metric is the objective function of the artificial society, we can recreate the same phenomenon as a real society[12.16].

12.4 Experiments

In this section, we describe experiments whether the sharing norm of information properties is stable or not. We constitute three kinds of society, and experiment about an amount of information, a free rider, an intolerant agent and information gap.

12.4.1 An Amount of Information in Each Society

We design the following three artificial societies:

1. Face-to-Face communication oriented society (FFS)
The communication among the agents is constrained by both the physical and mental coordinates. They interact with physical and mental neighborhoods. The ratio is parameterized.
2. E-Mail oriented society (EMS)
The communication among the agents is constrained by the mental coordinates. In this society, agents interact each other one by one at each step.
3. Net-News oriented society (NNS)
NNS is an extension of EMS. It has a virtual whiteboard at the center of The world. Agents in the world send messages to the whiteboard, and the whiteboard distributes the messages to all the agents. The credibility value of the messages is the same as the one of the senders.

We set one agent with a lot of information $\sum_{kd=1}^n e_{kd}^i w_{kd}^i$ participate in each society. Figure 12.1 shows the change of information amounts in each society after 300 periods of communication. Y-axis is an average of all agents' information amount and X-axis is the communication amount. The initial values of predetermined parameters are set to random. While the information amount of FFS changes slowly, the amount of EMS changes rapidly at some parts. The amount of NNS changes rapidly at a part, and then it is saturated at a burst.

We consider that the cause is the restriction of information. In EMS, a credibility distance decides a receiver. If the society forms a crowded group temporarily, the agents will communicate rapidly in the group and vice versa. In NNS, if an agent sends a worthy message, credibility of a forum where the agent participates will increase and the agents will communicate rapidly.

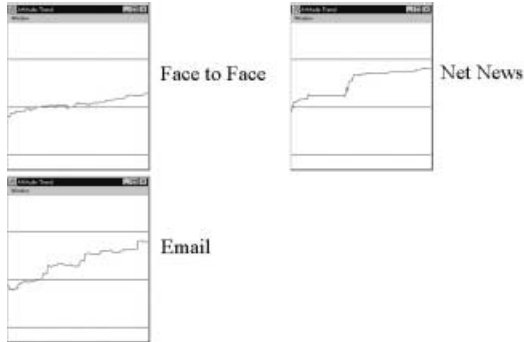


Fig. 12.1. The change of information quantity (300terms, 30agents/society)

12.4.2 Emergence and Collapse of a Norm

A society with the common sharing norm is advantageous. Such an advantage is observed in the rapid increasing of information in NNS. One agent tends to send messages to Netnews, because the agent can get more worthy information in NNS than FFS. Netnews is thought of as equipment that shares information resource in network society. It appears as phenomena that agents approach to Netnews. Figure 12.2 shows the experiments in NNS.

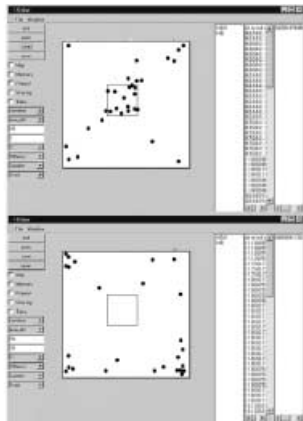


Fig. 12.2. Occurrence and collapse of norm in Netnews society(left: after 10terms, right: after 50terms, 30agents/society)

The center rectangle represents Netnews. In the early stage of communication and interaction among agents, posting and acquiring information via Netnews increases rapidly, then the agents concentrate to the center (the left figure). This indicates that maintenance of a communal sharing norm is the advantage for each agent.

In the second stage that agents communicate frequently, however, the agents leave from Netnews (the right figure). The cause is likely the uniformity of knowledge. It is difficult for agents to get new information in this stage.

It shows that if free riders that pay no cost for posting messages increase, Netnews will lose its worth.

12.4.3 Emergence and Control of Free Riders

Figure 12.3(the left figure) shows the change of average send-gene of all agents in FFS. It is one of predetermined parameters. Y-axis is average sending probability. X-axis is the amount of communication. Sending probability decreases slowly. It demonstrates free riders emergent in FFS. In FFS simulation results, we have also found the same phenomenon in EMS. An agent loses the energy for communication gradually, while it gets the energy for worthy information. The free rider can live forever because it doesn't send and only gets information. As the result, the amount of sending messages decreases, and agents who have the sharing norm lose the energy. Because they can't get worthy information, though they expect rewards as sharing for sending messages. Eventually all of them would go away.

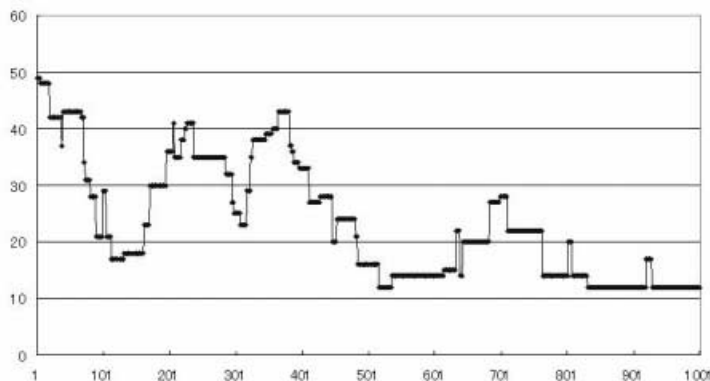


Fig. 12.3. The change of send-gene and the effect of tolerant agents. Left is increasing of free riders. Right is controlling of free riders (1000 terms, Average of 30 agents/society)

We extended the model not to send a message if the agent is a free rider. The result of the experiment is shown in Figure 12.3(the right figure) . Free riders can't get more information, and they lose their energy. As the result, decrease of send-gene is controlled in the society. So existence of intolerance agents can control free riders without an explicit punishment. It demonstrates the reason why implicit norms exist except explicit norms such as the law.

12.4.4 Information Gap

The information gap among agents and efficiency of information acquisition can be examined using Inverse simulation of TRURL, We can know the nature of information rich agents. The information gap can be measured with Gini index. Gini index is a sample statistic in economic categories and represents an income gap. The larger Gini index values means the more income gaps, that is, there are the more difference of incomes among the rich and the poor.

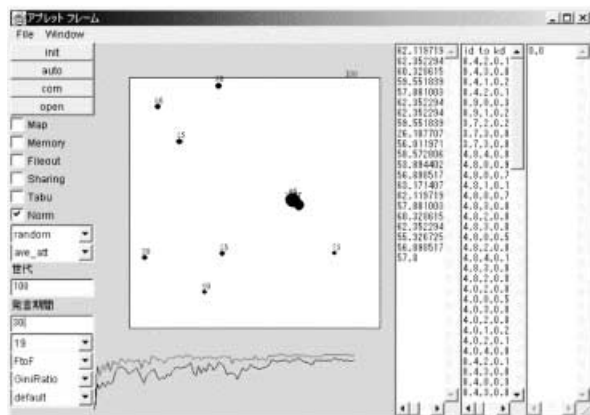


Fig. 12.4. Max Gini factor of FFS (100 terms, 300 generations, 20 societies, 30 agents/society)

$$Z_{Gini} = 1 - \frac{\sum_{i=1..N} ((2 \sum_{k=1..i} E_k - E_i) A_i)}{(E_{tot} A_{tot})}$$

sort data: $E_i/A_i > E_{i-1}/A_{i-1}$, A_i : "people" (population in $group_i$), E_i : "wealth" (the amount of information in $group_i$), $A_{tot} = \sum_{i=1..N} A_i$, $E_{tot} = \sum_{i=1..N} E_i$

As shown in Figure 12.4.4, we simulated 20 societies with Gini factor as an objective function. The results are that maximum Gini factors are 63% in FFS, 54% in EMS and 48% in NNS. It shows a relation as $FtoF > Email > Netnews$ (the upper part of Table 12.1).

Netnews society has less information gap than the other societies. We have observed the genes of the information rich agents in each society. In FFS, the rich agent is to send many messages (Probably 0.75) and to read them frequently (Probably 1.0). In NNS, the rich agent is to send few messages (Probably 0.20) and to read them occasionally (Probably 0.92).

These results suggest the following hypotheses: In FFS, the active agent, which gathers information by itself sends the information and listens to other agents frequently, can become the information rich. In NNS, the Net surfer

Table 12.1. The gap and nature of information rich persons / Difference of energies in each society

	FFS	EMS	NNS
Max Gini index	63%	54%	48%
Sending probability of the rich	0.75	0.63	0.20
Receiving probability of the rich	1.0	0.94	0.92
Max energy	54	77	165
Max energy ratio	1.0	1.4	3.1

agent, which sends few messages, can become the information rich. It reads information on the Net instead of gathering information spending costs, EMS is seated at the midpoint. In addition, we used the following objective function for the simulation. $\sum_{i=1}^n m_i : m_i \text{ is action energy of agent } i$

This maximizes the amount of action energy, which is the difference between information value and gathering cost. It indicates that the agents communicate their information efficiently and represents the efficiency of the society to gather information. The result is shown in the under part of Table 12.1.

NNS has the ability to gather information 3.1 times as much as FFS. Although the information rich agents exist in NNS, the information gap is less than other societies.

12.4.5 Discussion

When we observe the change of information in three societies, the following results are suggested: NNS has big communication ability, a free rider occurs in any society, an intolerance agent can control free riders, and the information gap in NNS is the smallest.

From the viewpoint of the communal sharing norm, the experimental results have implies the following items: Information property has a different nature from physical resources in terms of sharing. Sharing and distribution of information don't mean to reduce their property values. Netnews, which is an equipment to share information, can control free riders and reduce the information gap in NNS. On the contrary, agents, which don't participate to the Netnews society, might expand the information gap. Digital Divide might be one of these phenomena. So the results may persuade to change a definition of a free rider in NNS.

Before the experiments, our hypothesis was that the communal sharing norm would easily collapse and increase free riders in NNS such as an advanced information society, because the society wouldn't have severe morality like punishments and intolerance. However, the simulation results have refused the hypothesis. The information gap didn't expand more than our prediction in NNS. Although free riders emerged in NNS, they didn't collapse the

norms. Then we assumed that a manager of venture type easily gets richer than a manager of traditional type. However, the former types have become richer than the latter types.

12.5 Conclusion

This paper has described agent-based simulation and their experiments about a communal sharing norm. We have simulated several evolutionary artificial societies with multiagents. We have observed the emergence, collapse and control of norms in FFS, EMS and NNS. Using TRURL, we could analyze the nature of social interactions in the artificial world. We have also demonstrated that the technique of Agent-based Simulation could contribute to resolve organizations and social phenomena.

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13. Toward Cumulative Progress in Agent-Based Simulation

Keiki Takadama and Katsunori Shimohara

ATR International, Information Sciences Division
2-2-2 Hikaridai, Seika-cho, Soraku-gun, Kyoto 619-0288 Japan
{keiki,katsu}@isd.atr.co.jp

Abstract. This paper stresses the importance of focusing on modeling processes in order to make cumulative progress in agent-based approaches. In this paper, we introduce our approach to analyzing modeling processes and investigate its possibilities toward cumulative progress. The capabilities of our approach can be summarized as follows: (1) our approach has great potential to promote cumulative progress in agent-based approaches; and (2) the elements found by our approach have high possibilities of affecting the real world, being utilized as tool-kits, and supporting the KISS principle.

Keyword: agent-based approach, computational simulation, cumulative progress, modeling process

13.1 Introduction

An *agent-based approach* can provide techniques and tools for analyzing complex organizations and social phenomena. This approach explicitly examines organizing processes and social dynamics and builds theories by clarifying vague, intuitive, or under-specified issues in conventional approaches. Although research on agent-based approaches has recently attracted much attention, the approaches actually have a long history. Major examples originally included *garbage can model* [13.10], *iterated prisoner's dilemma (IPD)* [13.2], *multiagent soar* [13.6], and *Virtual Design Team (VDT)* [13.17]. Following these models, several others are proposed such as *sugarscape* [13.13], *ORGAEAD* [13.8], *PCANS*¹ [13.15], *simulating society* [13.14], and *agent-based computational economics (ACE)* [13.24].

These several models and methods contributed to our understanding of complex organizations and social phenomena. However, in Cohen's phrase, "disciplines or fields of study do not get much progress due to a lack of *cumulative progress* in agent-based approaches [13.12]." This indicates that agent-based approaches do not compel new investigators to build on the accomplishments of older works, even though these previous works provided a

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¹ This model is currently extended to PCANSS.

lot of useful results and showed high potential to understand other important issues in organizational and social science. So, what is a main cause of this problem? How do we overcome this problem? Unfortunately, these questions are left behind the colorful and powerful simulations. Since agent-based approaches cannot avoid tackling these questions, this paper aims to summarize the factors that prevent cumulative progress in agent-based approaches and shows that our approach offers possibilities of assisting cumulative progress in agent-based approaches.

This paper is organized as follows. Section 13.2 starts by describing the factors that prevent cumulative progress in agent-based approaches, and Section 13.3 explains our approaches toward cumulative progress. The potential and capabilities of our approach to promoting cumulative progress are discussed in Section 13.4, and our conclusions are finally made in Section 13.5.

13.2 Can We Assist Cumulative Progress?

13.2.1 Problems in Agent-Based Approaches

In the previous section, we pointed out that the main problem of agent-based approaches is the lack of cumulative progress. So, what has caused this lack of cumulative progress? There are many reasons. According to Cohen, “A lack of mathematical tools is a part of the problem. But, there are many other problems, including the way we train our students and evaluate research projects, with too little emphasis on building on what is known, and too much emphasis on novelty and on the promise of more powerful computation [13.12].”

13.2.2 Points for Cumulative Progress

Toward overcoming the above difficulties, it is useful to enumerate the points that promote cumulative progress in agent-based approaches. Considering Cohen’s claim, the following solutions offer significant toward cumulative progress.

- **(a) Common test-beds:** First, sharing common test-beds is a promising approach for cumulative progress. The reasons are summarized as follows: (1) common test-beds enable researchers to narrow an argument down to concrete and detailed issues, which help to providing a fruitful and productive discussion; and (2) common test-beds encourage researchers to share results, which leads to progress in the field by comparing results or competing with other researchers.
- **(b) Standard computational models:** Next, standard computational models are necessary for cumulative progress. This is because (1) researchers do not need to design computational models, which contribute to

bringing several researchers together toward a progress in the field; and (2) common parts of various research efforts become clear through the development of libraries of computational models, which provides the essential parts of agent-based simulations.

- **(c) Validation and advance of older works:** Third, it is important to validate older results and advance older works for cumulative progress. In this case, the replication of older models is essential to validate and advance older works. To promote this, researchers should share and understand what were done and what are not in agent-based approaches.
- **(d) Standard evaluation criteria:** Finally, standard evaluation criteria for results (including papers and projects) are indispensable for cumulative progress. Although it is difficult to evaluate results appropriately, it is important to apply the same evaluation criteria. For instance, a *benchmark* in evaluation criteria would be useful for cumulative progress.

In addition to the above points, the following points are also important to promote cumulative progress, though they are not restricted to agent-based approaches: (1) regular meetings that enable researchers to constantly share results; and (2) appropriate teaching of students.

13.2.3 Cumulative Progress in Current Projects

Based on the above four points, this subsection analyzes how current agent-based research can achieve these goals.

For *common test-beds*, the *U-Mart project* [13.19], for instance, is recognized as a common test-bed for a virtual stock market in the economic field. Although this project began a few years ago, it has promoted cumulative progress by narrowing arguments down to a concrete and detailed stock market and by sharing the results among researchers.

For *standard computational models*, Axelrod and his colleagues developed standard computational models by employing their existing models (such as *garbage can model* and *iterated prisoner's dilemma (IPD)*) [13.3]. Kurumatani is also developing libraries of standard parts in *World Trade League* [13.16], which aims to provide a multiagent-based universal environment for analyzing economic and financial systems.

Although these efforts have promoted cumulative progress, conventional agent-based approaches have not so far fully address the four points.

13.3 Exploring Key Elements

Since it is not easy to promote cumulative progress in agent-based approaches as described in the previous section, this paper starts by investigating how our approach [13.21] can promote such cumulative progress as the first stage of our research.

13.3.1 Interpretation by Implementation

Outline. The *Interpretation by Implementation (IbI)* approach is a *trial and error* method for seeking underlying elements of organizations or societies through a process of continuing the *implementation* and *interpretation* phases in turn. The concrete algorithm of the IbI approach proceeds as follows.

1. First, the IbI approach implements a model (*i.e.*, model A in Figure 13.1) while focusing on a modeling process. In this stage of the IbI approach, the following three processes are employed: (a) concept breakdown, (b) assumptions/premises modification, and (c) investigating layers change (all three detailed process will be described later).
2. Next, the IbI approach interprets results to investigate the underlying elements that determine the characteristics of multiagent organizations or societies.
3. If the essential elements are found, then this process is finished. If not, new models (*i.e.*, models B, C, \dots in Figure 13.1) are implemented to investigate other elements; then, goto 2.

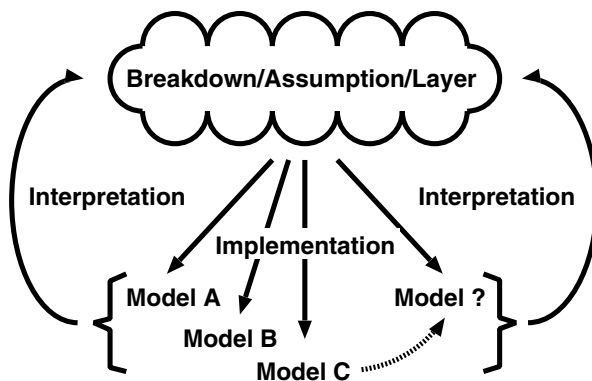


Fig. 13.1. Interpretation by Implementation

What is important to note here is that the IbI approach focuses on the influence of elements embedded in a modeling process on results. Since these elements have a big influence on results, we must consider such an influence when employing agent-based approaches. However, it is difficult to visualize these elements, and thus the IbI approach employs a trial and error method that explores essential elements by changing them.

Elements Embedded in a Modeling Process. From the previous section, the important point is to decide what kinds of modeling processes we should focus on. In this stage of the IbI approach, the following three processes are employed for the following reasons. Note that we never claim that the following three processes are sufficient for finding the underlying elements in

organizations or societies. Other viewpoints can be considered in addition to the following processes.

- **Concept breakdown:** When implementing a concept in a computational model, we must clarify abstract parts by breaking the concept down into detailed and operationalized parts from the computational viewpoint. Since characteristics of multiagent organizations or societies change depending on such a breakdown process, key elements are likely to be embedded in this modeling process.
- **Assumptions/premises modification:** We tend to implement computational models under assumptions or premises that are generally set unconsciously. This tendency increases as we concentrate on investigating issues. However, such assumptions or premises have a high possibility of being key elements because the results drastically change by varying assumptions or premises.
- **Investigating layers change:** When investigating characteristics of organizations or societies, some of the characteristics are found in a certain layer while others may be found in another layer. This indicates that a change in the layer for an investigation has the potential of finding new key elements that affect the characteristics of organizations or societies.

13.3.2 Applications of IBI Approach

This section briefly describes three applications of the IBI Approach.

Concept Breakdown. Organizational learning(OL)[13.1, 13.11] is roughly characterized as organizational activities that solve problems that cannot be solved at an individual level, and it has a large influence on the characteristics of organizations. However, the concept of OL can be implemented (broken down) in many ways from a computational viewpoint. Focusing on this feature, we found that the following three elements affect the characteristics of multiagent organizations through breaking the concept of OL down in a certain way [13.20]: (1) the independence of learning mechanisms; (2) the execution order of learning mechanisms; and (3) the combination of exploration at an individual level and exploitation at an organizational level. These implications can be revealed through the *implementation* of a concept breakdown and the *interpretation* of simulation results.

Assumptions/premises modification. As shown in the typical example of the *prisoner's dilemma* [13.4], agents are roughly divided into the following two categories: (1) the selfish or competitive type and (2) the altruistic or cooperative type. This classification effectively distinguishes *goals* of agents at individual levels from those at organizational levels. However, we found that an evaluation of agents affected the characteristics of multiagent organizations more than the goals of agents [13.22]. This implication cannot be revealed from a goal-related perspective but through the *implementation* of

varying premises by adding an evaluation perspective and the *interpretation* of simulation results.

Investigating layers change. One of the important problems in an organization is solving the trade-off between *exploration* and *exploitation* [13.18]. To address this issue, we focused on the fact that the trade-off between exploration and exploitation is not embedded in one layer but found in several layers. Then, we found that a certain problem-specific trade-off could contribute to solving the fundamental trade-off between solutions (related to exploration) and costs (related to exploitation) [13.23]. This implication cannot be revealed by only considering fundamental trade-offs but through the *implementation* of a framework that provides an investigation of other trade-offs and the *interpretation* of simulation results.

13.4 Discussion

13.4.1 Cumulative Progress

First, we discuss how our approach has the potential to promote cumulative progress in agent-based approaches. As mentioned in Section 13.2, the following four points are important for cumulative progress: (a) common test-beds; (b) standard computational models; (c) validation and advance of older works; and (d) standard evaluation criteria. Although conventional agent-based approaches do not encourage researchers to fully address the four points, our approach tackles them as follows.

- **(a) Common test-beds:** Since factors and assumptions embedded in a modeling process are mostly general, researchers not only can share results but also utilize factors. This indicates that our approach does not require common test-beds to share and utilize results. This advantage does not force researchers to adjust their ideas or methods to common test-beds.
- **(b) Standard computational models:** Factors and assumptions embedded in a modeling process are kinds of common parts in simulation models. Therefore, standard computational models can be developed by combining several kinds of factors and assumptions.
- **(c) Validation and advance of older works:** Factors and assumptions embedded in a modeling process are simple because they can be divided into each element. From this feature, it is easy to replicate older models if the factors and assumptions of older models are analyzed in advance, and such replication encourages researchers to validate older results. Furthermore, researchers have the chance to advance older works by simply adding and removing factors and assumptions.
- **(d) Standard evaluation criteria:** Since factors and assumptions embedded in a modeling process are independent from addressed issues, researchers can concentrate on evaluating the essential degree of these elements. For instance, we measure such factors and assumptions in terms

of degrees of influence on results, simplicity of implementation, and so on. These degrees in evaluation criteria can be considered as bench-marks in agent-based approaches.

From the above analysis, our approach has great potential to promote cumulative progress in agent-based approaches. However, we should not neglect the following point to effectively receive the advantages of our approach: it is important to (1) store a lot of factors and assumptions embedded in a modeling process and (2) systematize these elements in advance for easy utilization. If the above points are achieved, our approach enables us to understand what has been done and what remains to be done in agent-based approaches by simply investigating the repository of underlying factors and assumptions.

13.4.2 Potential of Our Approach

Next, we discuss the potential of our approach in terms of the following viewpoints: (1) linkage to real world; (2) tool-kits; and (3) the KISS principle.

Linkage to Real World. Linkage to the real world is one of the major problems in agent-based simulations. Even though many useful implications can be found in computational simulations, we cannot guarantee that these implications are valid in the real world. For this problem, Axelrod answered in his book as follows: “Although agent-based modeling employs simulation, it does not aim to provide an accurate representation of a particular empirical application. Instead, the goal of agent-based modeling is to enrich our understand of fundamental process that may appear in a variety of application. [13.4].” Carley, who proposed the concept of *computational organization theory (COT)* [13.7], responded as follows: “Human organizations can be viewed as inherently computational because many of their activities transform information from one form to another, and because organizational activity is frequently *information driven* [13.9]”. This assertion supports the effectiveness of computational analysis.

Concerning our approach which focuses on factors and assumptions embedded in a modeling process, these elements offer potential power to affect the real world. This is because the elements have a large influence on results even when they slightly change. Although simulation results do not follow the real world because the real world includes several kinds of unexpected factors and the observed phenomena only show one aspect of the real world, our approach can identify essential keys that affect the real world.

Tool-kits. Recently, a lot of agent-based simulators, including *Swarm*,² have been proposed and these have contributed to understanding complex organizations and social phenomena. However, the following important problems still remain: (1) agent-based simulators are mostly useful for visualization

² See <http://www.swarm.org> for details.

tools, not for computational simulation tools. This is because we have to design essential parts of simulations such as internal models of agents. (2) Agent-based simulators are often built for specific issues. Researchers also build their own tools instead of using tools built by others, and thus it is difficult to share the same agent-based simulators. These two problems clearly prevent cumulative progress in agent-based approaches. To overcome these problems, Axelrod devoted himself to developing general tools for agent-based approaches [13.3], but he finally gave it up, because most tools for social and organizational simulations have to be designed for specific tasks, and thus few parts can be shared or applied to other models [13.5].

In comparison with the above conventional agent-based simulators, our approach has the capability of extracting common parts of simulations by exploring factors and assumptions embedded in a modeling process. Since these common parts are mostly related to fundamental parts of an agent design and are not specific to addressed issues, they can be used as tool-kits. This indicates that our approach provides general tool-kits that are difficult to find by developing domain-specific tool-kits.

KISS Principle. The KISS principle³ proposed by Axelrod claims that simple models should be implemented to understand the fundamental processes in organizational or social phenomena [13.4].⁴ This suggestion implies that one can be confident of understanding results by knowing everything that went into the model. Note that the KISS principle does not merely claim to make everything simple but also to leave essential parts by removing non-essential ones. Based on this claim, one important question remains: how do we figure out the essential parts? According to Axelrod, one method is to conversely derive the essential parts by investigating results and facts [13.5]. However, this derivation requires *good* sense, and it is neither easy nor an application of the scientific method. In comparison with this situation, the factors and assumptions found by our approach have high possibilities of being essential parts because these elements change the characteristics of multiagent organizations or societies. Of course, all elements are not required to implement models, but it is significant to consider such elements as candidates before implementing models. From this advantage, our approach offers great potential to support the KISS principle in terms of finding essential parts.

³ This principle stands for the army slogan *keep it simple, stupid*.

⁴ Strictly, he pointed out that *assumptions* underlying the agent-based model should be simple and also claimed that the complexity of agent-based modeling should be in the simulated results, not in the assumptions of the model.

13.5 Conclusions

This paper stressed the importance of focusing on modeling processes toward achieving cumulative progress in agent-based approaches. In particular, this paper suggested that the analysis of modeling processes can help to find elements that directly affect the characteristics of multiagent organizations or societies. Furthermore, we also showed that these elements were useful for an alternative understanding of complex organizations or social phenomena.

By investigating the capabilities of our approach, we found the following two implications. First, our approach has great potential to promote cumulative progress in agent-based approaches in terms of (a) common test-beds, (b) standard computational models, (c) validation and advance of older works, and (d) standard evaluation criteria. Second, the elements found by our approach offer the high possibilities of affecting the real world, being utilized as tool-kits, and supporting the KISS principle.

However, this paper only discussed the high potential of our approach for cumulative progress and did not prove them in the real world. Furthermore, this paper did not specify the range in which our approach showed its effectiveness. These should be addressed in the near future. We also have to investigate when and what elements found by our approach should be considered for particular situations.

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⁵ The name V-Mart changed to U-Mart.

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14. Complexity of Agents and Complexity of Markets

Kiyoshi Izumi

Cyber Assist Research Center, AIST and PREST, JST
2-41-6 Aomi, Koto-ku, Tokyo 135-0064, Japan,
kiyoshi@ni.aist.go.jp,
<http://www.carc.aist.go.jp/~kiyoshi/index.html>

In this study we rethought efficient market hypothesis from a viewpoint of complexity of market participants' prediction methods and market price's dynamics, and examined the hypothesis using simulation results of our artificial market model. As a result, we found the two differences from the hypothesis. (a) Complexity of markets was not fixed, but changed with complexity of agents. (b) When agents increased the complexity of their prediction methods, structure of dynamic patterns of market price didn't disappear, but it can't be described by equation of any dimensions.

14.1 Introduction

Are you surprised if the performance of financial specialists' forecasts is the same as that of randomly generated forecasts?

In the field of economics, the theory of financial markets called the efficient market hypothesis was proposed in the 70s, and it has caused many arguments till today. By this hypothesis, the movement of the price of financial markets is a random walk, and cannot be predicted. Therefore, the performance of all the forecasts is the same. Theories of financial engineering, which developed greatly today, are based on this hypothesis, and they assume financial prices as the stochastic process.

Although many statistical verification of the hypothesis was performed using actual data, since the hypothesis included a market participant's expectation formation, it has not been verified directly. In recent years, however, the artificial market approach which builds a virtual market model and performs a simulation into a computer appeared, and researches in this approach try to verify the hypothesis directly[14.1, 14.2, 14.3].

This study rethinks the efficient market hypothesis from the new viewpoint of the relation between the complexity of market participants' prediction formulas and the complexity of the movement of a market price. And this study examines the hypothesis from the simulation result using the artificial market model.

14.2 The Efficient Market Hypothesis Seen from Complexity

The main points of the efficient market hypothesis are summarized as follows.

- Each market participant of a financial market takes in very quickly and exactly all the information related to the movement of a market price, and uses it for price expectation.
- The market price that determined by the dealings between such market participants is reflecting properly all the relevant information that is available at present.
- Therefore, there is no room for a certain person to find out the new relation between a market price and the available information, and to become advantageous from other persons. That is, the movement of a market price becomes a random walk driven only by new information, and nobody can predict it.

When the above-mentioned main points are recaptured from the viewpoint of complexity, the efficient market hypothesis contains the following things implicitly.

- In order to take in suitable information, each market participant is going to complicate his prediction formula by learning, and is going to hold the structure of the determination formula of the market price.
- The structure of a price determination formula is fixed and independent of the learning of market participants. Finally the market participants detect the structure, and it will disappear.

That is, the efficient market hypothesis needs the two premises: (a) the independence of the complexity of the movement of a market price from the complexity of each market participant's prediction formula and (b) the existence of motivation of leaning by each market participant.

On the other hand, by the artificial market simulation, de la Maza[14.4] found that when the dimension of market participants' prediction formula went up from 0 to 1, the movement of a market price also changes from a random walk to linearity. That is, he showed the possibility the complexity of market participants and the complexity of a market are not independent.

Then, what is the motivation to which each market participant complicates his prediction formula? Joshi et.al.[14.5] think that it is because the situation similar to the prisoner's dilemma game has occurred. In their artificial market model, taking in the technique of the moving average of a technical analysis to a prediction method, and raising the dimension of a prediction formula from 0 to 1 corresponds to the default strategy of the prisoner's dilemma game. On the other hand, not using a technical analysis for prediction corresponds to the cooperation strategy. From the simulation result, the two following conditions for becoming a prisoner's dilemma situation were seen.

Condition 1. If one raises his prediction dimension, his prediction becomes more accurate and the profit of his dealings result increases. Thus, the motivation of the default strategy exists.

Condition 2. However, when everybody raised the dimension, the movement of the market price became more complicated, and the prediction accuracy has fallen rather than the time of everybody's not using the technical analysis.

Thus, since everybody raised the dimension of his prediction formula in pursuit of profits, the prediction accuracy becomes worse than before.

In the following sections, by the artificial market simulation, we analyze the complexity of a market and the prisoner's dilemma situation when a prediction dimension becomes larger.

14.3 Artificial Market Model

The artificial market is a virtual financial market with 50 virtual dealers (agents) in a computer. One financial capital and one non-risk capital exist in this artificial market. Each agent expects the movement of the financial price, and he changes the position of the financial and non-risk capital so that the utility of his expected profit may become the maximum. In the artificial market, one term consists of four step of expectation, an order, price determination, and learning, and time progresses discretely by repeating these four steps.

14.3.1 Expectation

Each agent expects the change value of the financial price of this term using the weighted sum of the change value of past financial price. That is, in this study, since fundamentals information does not exist in a market, the agents expect the change value of the financial price only by the technical analysis.

The expectation formula of each agent is auto the regressive integral moving average model ARIMA($n, 1, 0$), where n means the number of the terms of the price changes used for expectation. The larger n is, the larger the dimension of an expectation formula is. Thus in this study, n is regarded as the complexity of each agent's expectation.

The expectation formula is as follows, when P_t is the financial price of this term which is not yet determined and \tilde{y}_t is the expectation the change of financial price ($P_t - P_{t-1}$).

$$\begin{aligned}\tilde{y}_t &= \sum_{i=1}^n b_i y_{t-i} + e_t \\ &= \mathbf{x}'_t \mathbf{b}_t + e_t\end{aligned}\tag{14.1}$$

Here, e_t is the normal distribution whose average is 0 and standard deviation is 0.1, \mathbf{b}_t is a vector with the coefficient of the prediction formula¹, $(b_1, \dots, b_n)'$, and \mathbf{x}_t is a vector of the explanation variables of the prediction formula, i.e., the past price changes², $(y_{t-1}, \dots, y_{t-n})'$.

14.3.2 Order

It is assumed that each agent has the utility function of expected profit with risk avoidance. Then the optimum quantity of the position of the financial capital with the maximum utility, q_t^* , is proportional to the expected change value y_t of the formula (14.1).

$$q_t^* = ay_t, \quad (14.2)$$

where a is a coefficient. Each agent's amount of orders o_t is the difference between the optimum position q_t^* and the current position q_{t-1} .

$$o_t = q_t^* - q_{t-1} \quad (14.3)$$

If the market price P_t is lower (higher) than his expected price ($P_{t-1} + y_t$), each agent order to buy (sell). The amount of order is o_t .

$$\text{If } o_t > 0 \begin{cases} \text{Buy } o_t & (P_t \leq P_{t-1} + y_t) \\ \text{No action} & (P_t > P_{t-1} + y_t) \end{cases}$$

$$\text{If } o_t < 0 \begin{cases} \text{No action} & (P_t < P_{t-1} + y_t) \\ \text{Sell } o_t & (P_t \geq P_{t-1} + y_t) \end{cases}$$

14.3.3 Price Determination

All the orders of 50 agents in the market are accumulated, and the market price of this term is determined as the value where the demand and supply are balanced. Dealings are transacted between the buyer who gave the price higher than a market price, and the seller of a lower price.

14.3.4 Learning

Each agent updates the coefficients \mathbf{b}_t of the prediction formula (14.1) using the successive least-squares method with the information on the change

¹ The initial value of the coefficients \mathbf{b}_0 is given with the uniform random numbers from -1 to 1.

² At the start, the initial values of price \mathbf{x}_0 are generated by the normal distribution whose average is 0 and standard deviation is 1.

y_t of the newly determined market price³. The least-squares method is as follows[14.6].

$$\mathbf{b}_{t+1} = \mathbf{b}_t + \frac{(\mathbf{X}'_t \mathbf{X}_t)^{-1} \mathbf{x}_t (y_t - \mathbf{x}'_t \mathbf{b}_t)}{f_t}, \quad (14.4)$$

where \mathbf{X}_t is a learning matrix which starts by $\mathbf{X}_0 = 100 \times \mathbf{I}$ (\mathbf{I} is a unit matrix), and is updated by the following formula.

$$\begin{aligned} (\mathbf{X}'_t \mathbf{X}_t)^{-1} &= (\mathbf{X}'_{t-1} \mathbf{X}_{t-1})^{-1} \\ &\quad - \frac{(\mathbf{X}'_{t-1} \mathbf{X}_{t-1})^{-1} \mathbf{x}_t \mathbf{x}'_t (\mathbf{X}'_{t-1} \mathbf{X}_{t-1})^{-1}}{f_t} \end{aligned} \quad (14.5)$$

$$f_t = 1 + \mathbf{x}'_t (\mathbf{X}'_{t-1} \mathbf{X}_{t-1})^{-1} \mathbf{x}_t \quad (14.6)$$

14.4 Simulation Result

In the next section, we examine the complexity of the market and the prisoner's dilemma-situation when the prediction dimension became large using the artificial market model.

14.4.1 Merit of Complicating a Prediction Formula

We investigated the merit of complicating the prediction formula. The dimensions of 25 agents' prediction formulas was set to n , and the dimension of the prediction formula of the other 25 agents was $n + 1$. Each simulation had 4000 terms which consisted of the four steps in section 14.3. The averages of forecast errors were calculated both about the agent group with n dimensions and about the group of $n + 1$ dimensions. The forecast errors were the difference between each agent's prediction value and a market price. The initial value of random numbers was changed and 100 simulations was carried out⁴. Figure 14.1 shows the difference between the forecasts errors of the group with $n + 1$ dimensions and those of the group of n dimensions.

While the number of dimensions in the prediction formula is small, the merit of complicating prediction formulas is large. The agent who can predict correctly can increase his profit. Thus, when the number of dimensions is small, the conditions 1 of the prisoner's dilemma situation in the section 14.2 are hold. However, when the number of dimensions becomes large, the merit of complicating prediction formulas disappears.

³ When $n = 0$, the prediction value is a random number and learning is not performed.

⁴ Since the calculation of averages were impossible when the market price had diverged, we carried out simulations until we could get 100 simulations whose paths did not diverge.

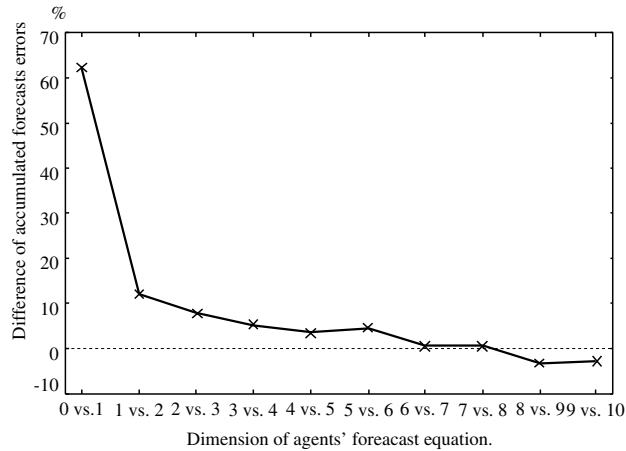


Fig. 14.1. Comparison of forecast errors: Y-axis is a difference of forecast errors (forecast errors of the group of n dimensions are 100). Positive (negative) values mean that forecast errors of the group of $n + 1$ dimensions are small (large).

14.4.2 The Demerit in the Whole Market

We examined whether the prediction of prices becomes harder in the whole market as increase of the dimension of prediction formulas. In this simulation, 50 prediction formulas of all agents were the same n dimension. We carried out the simulation with 4000 terms 100 times⁵. After having accumulated the forecasts errors in 4000 terms and taking an average of 50 agents in 100 simulations. (Fig.14.2).

As a result, when the number of dimensions in the prediction formula was small, the forecast error became large, as the number of dimensions increased. That is, the conditions 2 of the prisoner's dilemma situation in the section 14.2 were hold. However, it has converged to the fixed value when the number of dimensions was larger than three.

14.4.3 Development of the Complexity of a Market

In order to examine the independence of the complexity of the movement of a market price from the complexity of each market participant's prediction formula, we carried out the correlation dimension analysis⁶. All 50 agents have the prediction formulas of the same n dimension. We carried out the simulation with 4000 terms 100 times. Changed the embedding dimensions,

⁵ The path to diverge was not seen when all agents' prediction formula was the same dimension.

⁶ The procedure of the correlation dimension analysis was described in [14.7, 14.8].

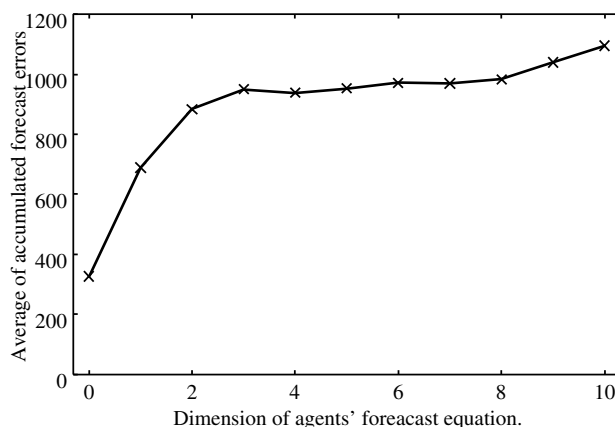


Fig. 14.2. Forecast errors

the correlation dimensions was calculated using the price data of 3885 terms at the second half while learning were stabilized to some extent (Fig.14.3).

As a result, when a prediction dimension was 0, the correlation dimension curve was convex downward like the theoretical value of a random walk (fig. 14.3a). That is, there is no structure in the dynamics of the market price. However, when the prediction dimension increase a little, the correlation dimension curve was convex upward and saturated (fig. 14.3b). Thus, the structure that could be described by an equation of a finite dimension appeared in the dynamics of the market price. Furthermore, when the prediction dimension was raised, the correlation dimension curve became a straight line (fig. 14.3c). Thus, the correlation dimension curve was neither convex downward like a random walk nor saturated. That is, there was a structure in the dynamics of the market price, but it could not be described by an equation of any finite dimension.

According to Nakajima [14.7, 14.8], as a result of analyzing Tokyo Stock Exchange Stock Price Index data, the logarithm of a correlation dimension went up linearly like this simulation result in fig. 14.3c. That is, when each agent's prediction dimension increases, like the price data in the real-world, the dynamics of the price in the artificial market can be described roughly by an equation of some dimensions. And the more precise description is also attained by increasing the number of dimension. However, the movement of price data cannot be described completely by an equation of any finite dimensions. That is, the number of the variables related to the movement cannot be specified completely.

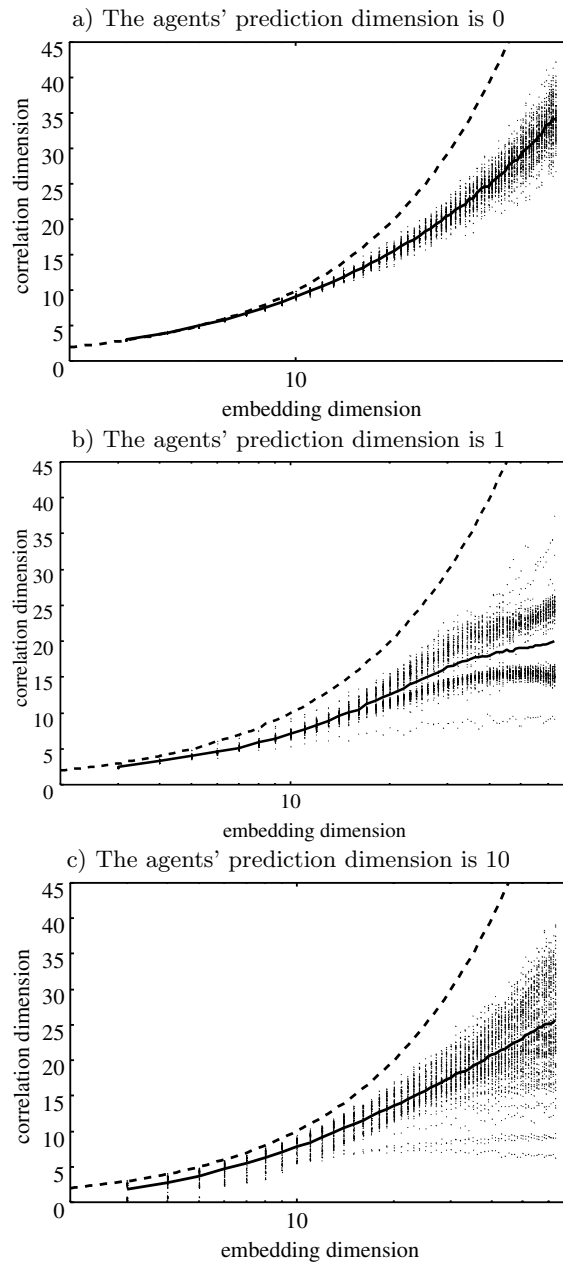


Fig. 14.3. Correlation dimensions : X-axis is the logarithm of embedding dimensions. A solid line is an average of the correlation dimension of 100 paths. A dotted line is the theoretical value of a random walk.

14.5 New Efficient Market Hypothesis

The simulation results are summarized as follows.

- When each market participant’s prediction dimension is 0, the movement of a market price resembles a random walk. If the prediction dimension increases, the structure that can be described by an equation of a finite dimension appears in the movement of price.
- Therefore, if each agent increases his prediction dimension, since the prediction dimension approaches to the dimension of the price determination formula and his prediction becomes more accurate. Thus, the merit of complicating prediction formulas exists. However, if everybody increases his or her prediction dimension, prediction accuracy becomes smaller than before. That is, it will become the prisoner’s dilemma situation.
- If everybody continues to increase the prediction dimension in the prisoner’s dilemma situation, the movement of a market price come to have the structure that can not be described completely by an equation of any finite dimensions.

The structure of the movement of a market price changed as market participants changed their prediction formulas. That is, the complexity of market participants and the complexity of a market are not independent unlike the efficient market hypothesis. The simulation results also suggest that the structure of the dynamics of price data did not disappear when market participants continue to complicate their prediction formulas. In the final state, however each market participant increases his prediction dimension, he cannot predict the market price completely.

In such the state where there is no “correct answer” of learning, it is thought that a procedure of learning by each market participant becomes the key factor to the movement of a market price in addition to a result of learning. As Kichiji[14.9] said, the efficiency of learning by a market participant, the difference in the cognitive framework, the interaction between market participants, and the method of informational choice, etc. become important.

Another key point is the mechanism of market price determination. In this study we assumed that the market price were determined discretely as an equilibrium price. Alternatively we can assume that the market price is determined continuously as transaction prices of dealings. The mechanism of market price determination is the mechanism how to accumulate the individual complexity on the complexity of a market. Therefore, it has large influence on the relation between the complexity of market participants’ prediction formulas and the complexity of the movement of a market price. It is interesting to examine whether the same simulation can be acquired when the mechanism of market price determination changes.

14.6 Conclusion

This study examined an efficient market hypothesis using artificial market approach. As a result, the following two points different from an efficient market hypothesis were found.

- While the prediction dimension of agents is small, the structure which can be described to the movement of a market price exists, and the motivation of increasing the prediction dimension exists.
- Even if the market participant increases the prediction dimension, the structure of the movement of a market price does not disappear. Finally, however each market participant increases his prediction dimension, he cannot predict the market price completely.

As future works, we want to investigate the influence of (a) the procedure of learning by a market participant and (b) the mechanism of the price determination on the relation between between the complexity of market participants' prediction formulas and the complexity of the movement of a market price.

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15. U-Mart Project: Learning Economic Principles from the Bottom by Both Human and Software Agents

Hiroshi Sato¹, Hiroyuki Matsui², Isao Ono³, Hajime Kita⁴, Takao Terano⁵, Hiroshi Deguchi², and Yoshinori Shiozawa⁶

¹ Dept. of Computer Science, National Defence Academy, Hashirimizu 1–10–20, Yokosuka, Kanagawa JAPAN, e-mail: hsato@nda.ac.jp

² Graduate School of Economics, Kyoto University, JAPAN

³ Faculty of Engineering, University of Tokushima, JAPAN

⁴ National Institution for Academic Degrees, JAPAN

⁵ Graduate School of Systems Management, University of Tsukuba, JAPAN

⁶ Faculty of Economics, Osaka City University, JAPAN

U-Mart is an interdisciplinary research program of agent-based artificial market. U-Mart proposes an open-type test bed to study trading strategies of agents, behavior of the market and their relationship. An experiment open to public (Pre U-Mart 2000) using the proposed system is held in August 2000. More than 40 software agents (computer programs for trading) from 11 teams participated in this experiment. This paper reports the outline of the experiment, the trading strategies of the participated agents and the results of the experiment. While Pre U-Mart 2000 treated only software agents, the U-Mart system is designed considering participation of the human players as well as the software agents. A gaming simulation by human using the U-Mart system held in Kyoto University is also introduced briefly.

15.1 Introduction

Complex behavior of market economy, typically observed in financial markets, is not fully explained by conventional economic theories. A new approach to this problem is an artificial market which enables computational experiments on virtual markets using agent simulation[15.1].

Studies on artificial markets have achieved a variety of interesting results. However, they also clarified the difficulties peculiar to this agent simulation approach, such as that:

- researchers from different fields need to cooperate due to the interdisciplinary nature of this approach,
- it is not easy to design a model which combines complexity (to imitate real markets) and simplicity (to enable computational experiments), and
- researchers need to share common understanding on experimental configurations and results which are more complicated than theoretical models.

U-Mart¹[15.2, 15.3, 15.4] is a research program to address these problems of artificial market studies. We have developed an artificial market simulation system, called U-Mart system, to provide a test bed for researchers from economics and information science to carry out experiments with common understanding. We are promoting diversified researches on markets by opening this system to public.

We have conducted an open experiment, Pre U-Mart 2000, on this system, inviting more than 40 software agents from public. This paper reports the result of the experiments, along with the strategies of the participated agents. The U-Mart system is designed to allow human players to participate in market experiments. This paper briefly introduces the human gaming simulation conducted at Kyoto University as well.

15.2 Outlines of U-Mart System

In the U-Mart system, ‘futures’ of real stock index are traded in a virtual market. This allows the market simulation environment to reflect the complexity of real markets, and at the same time, enables independent price formation. The U-Mart system is implemented as a client-server system, which exchanges information, such as buying and selling, via the Internet using a dedicated protocol implemented on TCP/IP. A server, which imitates an ‘exchange’, accepts orders from clients, determines prices, matches buying and selling orders, and manages clients’ accounts. Each client obtains the information, such as market performance, from the server and places order under its own decision. In the U-Mart system, human agents, as well as software agents, are allowed to participate in market experiments. Details of the U-Mart system are provided in [15.4].

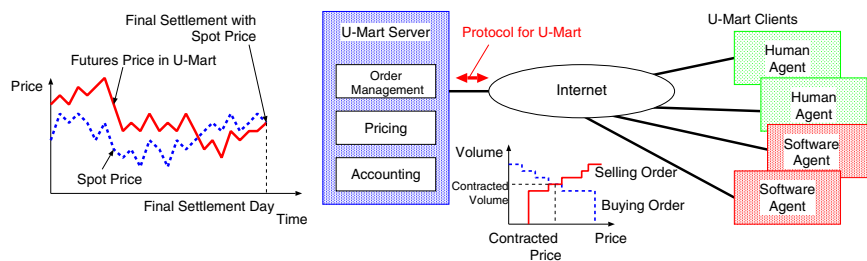


Fig. 15.1. U-Mart Artificial Market System

¹ originally called V-Mart

15.3 Outline of Open Experiment, Pre U-Mart 2000

15.3.1 Open Experiment and Its Objectives

We conducted an open experiment, Pre U-Mart 2000, on August 19th, 2000 as a part of 6th. Emergent System Symposium of The Society of Instrument and Control Engineers in Japan.

The objectives of this experiment are: to investigate variations of trading strategies and development methods for software agents, and to verify the actual behavior of market simulation among independently developed agents. Since it is the first open experiment for us, we limit the entry only to software agents. This is the reason that we name it “*Pre U-Mart 2000*”, which targets only a part of U-Mart conception. The participants have received an agent development package of U-Mart system in advance. This package contains templates of simple software agents and track record of J30 stock indices (used as spot data).

15.3.2 Experimental System

At the occasion of the experiment, Pre U-Mart 2000 committee set up a server machine, and the participants run agent programs on their note PCs connected to the server via Ethernet. The participants and the audience can watch the progress of the experiment through a video projector.

We tested the operation of the system on the first day of the symposium (August 18th.), and conducted the experiment in the afternoon of August 19th.

15.3.3 Configuration of Experiment

The price determination and contract algorithms are described in [15.4]. Table 15.1 shows the parameters for the market. We use Dow Jones Industrial Average (scaled to J30 equivalent) to prevent participants from estimating the spot market data from distributed J30 data.

The exchange (server) settles the accounts of agents at the end of one virtual day. When cash balance of an agent is less than zero after the settlement, the exchange automatically loan the agent up to its loan limit. The loan costs interest of 10% per annum and the exchange collect it at the settlement of the next virtual day. An agent goes into bankruptcy if the cash balance is still less than zero after obtaining the maximum loan, then the agent is not allowed to make any more deal.

15.4 Participated Agents and Their Strategies

Eleven teams participated in the experiment, seven from engineering and four from economics. Each team was assigned a quota of five agents.

Table 15.1. Parameters of Pre U-Mart 2000

Item	Setting
Underlying Indices	Dow Jones Industrial Average, scaled to J30 equivalent
Period	60 virtual days
Order Methods	market order/limit order
Pricing Method	ITAYOSE*
Pricing Interval	15 seconds (real time)
Number of Pricing	4 times/virtual day
Trade Unit	1000-fold of contracted indices
Bid and Asked	indices in increments of one point
Price Range	no restriction
Margin Money	300,000 YEN/Trade Unit
Settlement System	mark-to-market at closing price of the day
Membership Fee	none
Cash on Hand	1 billion YEN/agent
Loan Limit	30 million YEN

* A pricing method that accumulates orders for a certain period, and decides a price so as to achieve the maximum contracted volume for the accumulated orders.

The basic strategies of participated agents are mainly based on time-series analysis (technical analysis) or the price difference between spot and futures markets². Some agents have been manually programmed and the others use learning/adaptation methods such as GAs and neural networks. There are other interesting agents such as: the one refers to buying and selling behaviors of other agents, the one implements explicit risk management, and the one learns in real time basis. The followings describe the strategies of each team.

1. University of Tokushima team (Engineering): #1 - #5
 - Authors: Takao, I.Ono, N.Ono
 - Strategy: Some of their agents have learned neural networks (input: time-series of price differences, output: buying/selling) using GA. The other agents implement technical analysis methods, such as moving average, oscillator[15.5], and psychological line.
2. Kyoto University team (Economics): #6 - #10
 - Authors: Koyama, Zaima, Matsui, Deguchi
 - Strategy: Some of their agents place orders based on the deviation between short-term and very short-term moving averages. The other agents implement the improved version of psychological line. Contrivances have been made on number and amount of orders (for example, to make larger buying in the morning).
3. Tokyo Institute of Technology - Fukumoto team (Engineering): #11 - #15

² Actual futures markets allows a strategy called "arbitrage", which gains profit margin from the price difference by combining futures deals and spot deals. Since U-Mart only allows futures deals, the pure "arbitrage" strategy can not be implemented.

- Author: Fukumoto
 - Strategy: Their agents predict market trend with regression equation, and place orders based on deviation between current spot price and futures price. The parameters are learned with GA. They manage positions and implement bullish/bearish.
4. Tokyo Institute of Technology - Yamamura Lab. team (Engineering): #16 - #20
 - Authors: Yamashige, Kira, Ishii
 - Strategy: Some of their agents have learned neural networks (input: deviation between gradient of moving average and closing price, and deviation between lowest and highest prices in the past, output: expected price) using a hybrid algorithm. The other agents are: the one sells/buys at crests and troughs of price movement, and the one places orders after comparing its position with price difference between spot and futures markets.
 5. Univ. of Tsukuba and Yamatake Industrial team (Engineering): #21 - #25
 - Author: Murakami
 - Strategy: Their agents implement real-time learning of futures price prediction using classifier system, F-OCS. The agents have learned heavy rises and falls of markets and have incorporated the skills to cope with them.
 6. Osaka Pref. University team (Engineering): #26 - #30
 - Author: Mori
 - Strategy: The parasitic agents which do not use price information. They depend only on ordering information of other agents and place the same orders with majority.
 7. Osaka Sangyo Univ. team (Economics): #31 - #35
 - Authors: Taniguchi, Ozaki
 - Strategy: Some of their agents place orders according to the trend and against the trend. The other agents react to the gradient of price movement sensitively.
 8. National Defense Academy - Sato team (Engineering): #36 - #40
 - Author: Sato
 - Strategy: Their agents implement basic day-trading. They place selling order with few percent higher and purchase orders with few percent lower than the closing price of previous virtual day and aim at the profit from the difference between them.
 9. Kyoto Sangyo Univ. team (Economics): #41 - #45
 - Author: Nakashima
 - Strategy: Some of their agents place buying orders only or selling orders only base on dollar cost averaging method. The other agents place orders based on the 'ren-gyo-soku' method, a method of technical analysis.
 10. National Defense Academy - Ishinishi team (Engineering): #46 - #50
 - Author: Ishinishi
 - Strategy: Their agents place buying order when spot price is higher than futures price, and place selling order when spot price is lower than futures price.
 11. Osaka City University team (Economics): #51 - #55
 - Author: Shiozawa
 - Strategy: Basic technical analysis.

15.5 Experimental Result

We have conducted the experiments twice with different spot price series. The numbers of attended agents are 47 for the first round and 43 for the second round. Not every team uses its full quota of five agents.

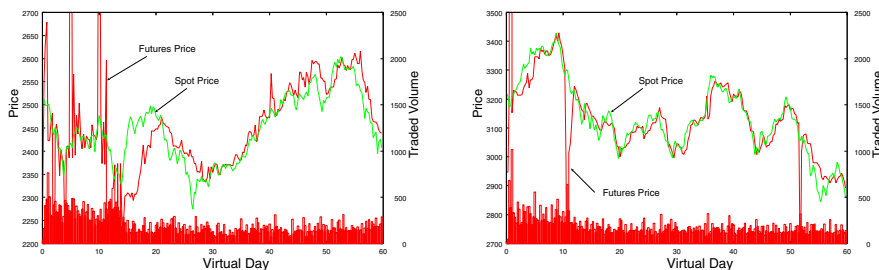


Fig. 15.2. Prices and Traded Volumes for 1st. Round (left) and 2nd. Round (right)

Table 15.2. Top 10 Performance of Agents for 1st. and 2nd. Round

1st. Round			2nd. Round		
Agent	Profit*1	Team*2	Agent	Profit*1	Team*2
#41	3,960,884	9	#12	3,005,755	3
#27	582,474	6	#13	1,792,902	3
#26	380,437	6	#18	1,686,144	4
#7	317,955	2	#19	820,168	4
#5	310,538	1	#43	710,379	9
#33	307,773	7	#44	388,575	9
#21	266,145	5	#27	285,245	6
#28	258,410	6	#7	254,108	2
#16	225,309	4	#16	206,260	4
#30	204,743	6	#9	197,120	2

*1: price unit: 1,000 YEN, *2: team is represented by their entry number

15.5.1 First Round

The spot price series for the first round repeats up and down several times and ends at the beginning price. Figure 15.2 (left) shows the transitions of price and trade volume. Table 15.2 and 15.3 show the performance of each agent and each team at the end of the game.

The heavy rises and falls are repeated at the beginning because of excessive limit order and market order combinations. Five agents go into bankruptcy during 11th. and 14th. virtual days. No agent goes into bankruptcy

Table 15.3. Performance of Teams at Pre U-Mart 2000

Team	1st. Round	2nd. Round
Kyoto Sangyo Univ.	2,717,039	-1,059,526
Osaka Pref. Univ.	1,512,561	-4,309,662
Univ. of Tokushima	661,096	-1,393,736
Kyoto Univ.	635,519	-1,175,857
Sato (NDA)	622,257	111,153
Osaka Sangyo Univ.	501,101	-1,504,747
Yamamura Lab. (TIT)	358,853	2,751,064
Univ. of Tsukuba and Yamatake	332,358	192,780
Osaka City Univ.	156,941	-53,780
Fukumoto (TIT)	-232,420	4,079,164
Ishinishi (NDA)	-4,711,406	-99,237

descending order of 1st. round profit (unit: 1,000 YEN)

before 11th. because rises and falls do not occur at the closing price, which directly affect to the end of the day settlement (c.f. 2nd. round). After the five agents go into bankruptcy, the market calms down and the deals are made around the spot price. The trade volume increases at the rapid price movements because of the huge volume of market orders.

15.5.2 Second Round

The spot price series for the second round shows long-term downtrend. Figure 15.2 (right) shows the transitions of price and trade volume. Table 15.2 and 15.3 show the performance of each agent and each team at the end of the game.

The second round shows only a few times of rapid price movements. This is because the price movement at the first day is too big (the futures price is 19,332 YEN, while the spot price is 3,178 YEN) and the market closes at this price. Three agents go into bankruptcy and the other agents are damaged seriously as well. Consequently, the trade volume decreases after the second day. Two more agents go into bankruptcy on 12th. day because of the huge price movement at the closing. Total of five agents go into bankruptcy on second round. The trade volume increases at the rapid price movements because of the huge volume of market orders.

15.5.3 Variety of Agents

Eleven teams participated in these experiments and the variety of the agents exceeded our expectations.

When agents show similar behavior, deals tend to fail because their decisions are similar. In such a case, to achieve deals, agents which place random

orders need to be introduced on the market. In our experiments, the prices have been formed between the varied agents without random agents.

Although several teams use the same analysis methods (moving average and psychological line), the final asset of these teams differs remarkably. This means that these teams interpreted the indices differently in implementation of the methods as software agents. Technical analysis indicates “the time to buy (or sell)”, but it does not recommend “the amount to buy (or sell) in which price”. We expect that this point is clarified with larger number of experiments.

It is interesting that the agents #41-45 (selling only/buying only) and #26-30 (do not use price data) have made good results especially on the first round. It does not mean that these strategies are always effective. However, they are obviously against the common practice that winners need to predict the future based on price data and to manage their position appropriately. Their successful performance contribute to the variety of agents.

In the future, more agents will implement the position management (implemented only on #11-#15) or the online learning for real-time modification of strategy (implemented only on #21-#25).

15.5.4 Reason of Heavy Rises and Falls

The heavy rises and falls occur at the beginning of both rounds. At these experiments, we have not restricted the price range and the agents are allowed to place orders at unrealistic price. Although these unrealistic orders normally do not affect price determination, they may be contracted when huge volume of market orders are placed. In the price determination algorithm of U-Mart system, selling market orders are considered as “limit orders lower than the lowest limit order” and buying market orders are considered as “limit orders higher than the highest limit order”. This makes the price formation vulnerable to huge volume of market orders (See Figure 15.3).

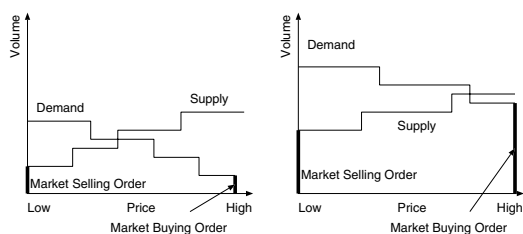


Fig. 15.3. Price Determination by ITAYOSE: When limit orders are dominant (left); When market orders are dominant(right).

There are two types of agents which place excessive orders. One type gives “very low buying limit and very high selling limit” (i.e. #38) and another type gives “very low selling limit and very high buying limit” (i.e. #35). We had assumed that they do not affect the market because the former

type has difficulty in making deal and the latter type goes into bankruptcy immediately. However, they have hazardous nature to rattle the market in relation with market orders. We may need to restrict the price range or to reconsider the price determination method.

15.6 Experiments with Human Agents

Heavy rises and falls have resulted at the beginning of the experiments with software agents. What happens if more sophisticated human agents deal in this virtual market? The U-Mart system can answer this question since it is designed to allow human agents to participate in market experiments.

As an example of the behavior of virtual markets constructed by human agents, this section introduces the experiments conducted at Kyoto University as a part of a lecture on gaming simulation³.

The experiments with human agents have been conducted three times under the similar conditions as Pre U-Mart 2000, using different spot data for each time. In these experiments, small number of software agents are introduced on the market. They place limit orders at the prices determined by random numbers which comply with normal distribution around the spot price.

Initially, the students made deals without strategy. It was natural because they were not familiar with the client software and they did not know much about futures markets or futures trade mechanisms. However, they started to understand these mechanisms by accumulating experience and became more strategic.

The result of third experiment (conducted on November 16th.) is shown in Figure 15.4. It shows the transition of the spot price, the virtual market price (U-Mart Price), and the asset position of each agent. In this experiment, a software agent has made the best profit among one software agent and seven human agent (including one faculty), and three students go into bankruptcy.

According to the students' reports after the experiments, the bankrupt students predict down-trend of spot price in long-term. They focuses on buying initially and continues selling after that, then go into bankruptcy along with the up-trend of spot price. On the other hand, the profited students respond to short-term price movements. They make small profits with a general strategy, that is to sell when price increases and to buy when price decreases. They maintain the stable position.

The experimental results show remarkable differences on behavior of human agents and the present software agents. Human agents not only make

³ "Economics System Gaming" (Dr. Deguchi) given at School of Economics, Kyoto University. This is a two class period on end (180 min.) biweekly lecture geared to undergraduate and graduate students.

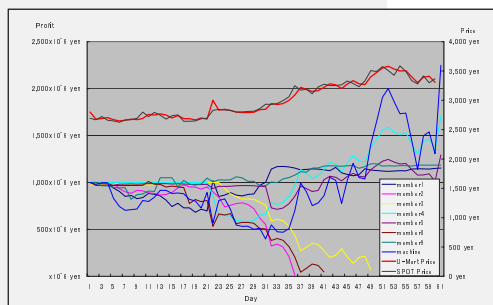


Fig. 15.4. Experimental Result with Human Agents

technical analysis of short-term price movement, but they predict long-term market trend and conceive a strategy based on impression.

Although the software agent has made the best profit in this experiment, it highly depends on contingency in connection with the used spot data and the strategies of human agents. From now on, more experimental cases need to be accumulated to analyze U-Mart as a market and to examine differences between human and software agents. We will also look into the availability of this system as an educational tool.

15.7 Conclusion and Acknowledgements

In this paper, we have reported on the experiments of open-type artificial market, U-Mart, conducted with software agents and/or human agents. The results of experiments have shown the possibility to construct a variety of software agents and clarified the strategic differences between human and software agents. We will carry this study program forward by integrating the knowledge obtained from both type of agent simulations. It is also interesting that the results indicated the usefulness of the U-Mart system as an educational tool for both economics and information science.

At the last, we are grateful to the participants of Pre U-Mart 2000 and everyone concerned with 6th. Emergent System Symposium. Also, we would like to thank Dr. Deguchi, Graduate School of Economics, Kyoto University, who provides the opportunity of human agents simulation using U-Mart system, and the students participated in the experiments.

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16. A Multi-objective Genetic Algorithm Approach to Construction of Trading Agents for Artificial Market Study

Rikiya Fukumoto¹ and Hajime Kita²

¹ Interdisciplinary Graduate School of Science and Engineering,
Tokyo Institute of Technology, Yokohama 226-8502, JAPAN

² National Institution for Academic Degrees,
3-29-1 Otsuka, Bunkyo, Tokyo 112-0012, JAPAN
kita@niad.ac.jp

To construct agents that have trading strategies with adequate rationality and variety is an intrinsic requirement for artificial market study. Difference of preference to return and risk among agents will be one candidate reason of variety of the trading strategies. It can be treated as a multi-objective optimization problem taking both criteria as objective functions. This paper proposes a multi-objective genetic algorithm(MOGA) approach to construction of trading agents for an artificial market. The U-Mart system, an artificial market simulator, is used for a test bed. Agents are evaluated in the U-Mart with other agents having simple strategies, and evolved with the MOGA. Computer simulation shows that various agents having non-dominated trading strategies can be obtained with this approach.

16.1 Introduction

Recognizing complex behaviors of the prices in the real markets and limitation of conventional theories in economics, analysis of markets using agent based simulation, called artificial markets, attracts attention[16.1, 16.2, 16.4]. In some of simulation models for artificial market, rather simple agents are employed so as to establish clear relationship between microscopic behavior of the agents and macroscopic behavior of the market. On the other hand, some of the models use more complex agents to study adaptation, learning, and evolution of the agents in the market. For the artificial market study, it is required that the agents should have trading strategies with adequate rationality as a model of microscopic economic behavior on the one hand, and on the other hand, their strategies should have variety to form price in the market. To construct agent meets such requirements is, therefore, a one of key issues in artificial market study.

In this paper, considering difference of preference to 'return' and 'risk' among agents as one of the important reasons of variety of the trading strategies, problem of designing agents is studied as a multi-objective optimization

problem taking the both criteria as objective functions. A multi-objective genetic algorithm(MOGA) is taken as an approach to construction of trading agents. For this study, the U-Mart system, an artificial market simulator, developed as a common test bed in this field is used.

This paper is organized as follows: succeeding to introduction in this section, the U-Mart System and the Multi-Objective Genetic Algorithms are briefly explained in Sections 2 and 3, respectively. In Section 4, the structures of the agents and implementation of the MOGA for this study is described. Section 5 shows the results of numerical experiments. Section 6 concludes this study.

16.2 The U-Mart System

For study of variety of trading strategies, learning and evolution of them, emerging behaviors of the market with them, and indirect control of the market through institutional design, artificial market systems with adequate complexity are required. Inspired by the RoboCup[16.6], the ‘U-Mart’ research program have organized and the U-Mart system has been developed[16.4].

The U-Mart system has following characteristics:

- In the U-Mart, futures of an existing stock index is traded. Thus, complexity of the real world is introduced keeping ability of autonomous price forming in the artificial market.
- The U-Mart system can be used for experiments with program agents, human traders, and their mixture. Thus it makes various research plans both in the communities of economics and computer science possible.
- The U-Mart takes server(futures market)-client(trading agent) structure over TCP/IP. Communication between the server and client is regulated by a readable text-base protocol called the Simple Virtual Market Protocol(SVMP). It makes development of servers and trading agents in parallel on various platforms, and experiments over the Internet possible.
- The U-Mart server is implemented in Java considering experiments on various platforms.

In August 2000, the first open trading contest limited to program agents (Pre U-Mart 2000) was held. More than 10 teams both from economics and computer science fields participated. This experiment shows that feasibility of the research program. Further, the U-Mart system has also been used for education both in the computer science and economics[16.5].

16.3 Multi-objective Genetic Algorithms (MOGA)

Multi-objective Optimization Problem (MOP) is a problem of optimizing multiple objectives simultaneously. In general, there exists trade-off among

objectives, and therefore usually no single solution can be the optimum. As rational solutions of the MOP, non-dominated solution (or the Pareto optimal solution) is considered. The non-dominated solution is a solution that has at least one objective function whose objective value is better than that of any other solutions. Hence, the goal of the solver for the MOP is to obtain the set of the non-dominated solutions called ‘the Pareto optimal set’.

Genetic Algorithms (GA) are optimization technique inspired by the natural selection theory of evolution[16.7, 16.8]. In the GAs, population of candidate solutions are evolved by repetitive application of genetic operators such as selection/generation alternation, crossover/recombination, and mutation. Multi-objective Genetic Algorithms(MOGA) are GAs that try to obtain various Pareto optimal solutions of a MOP simultaneously making use of the population-based search of the GAs[16.9].

MOGA is constructed by extending a single objective GA by introducing

- Mechanisms of selecting non-dominated solution among population as survivors to make population evolve closer to the Pareto optimal set.
- Mechanisms of maintaining diversity of the population to make the population cover the whole Pareto optimal set well.

Details of implementation of the MOGA in this study is discussed in the next section.

16.4 Construction of Trading Agents with a MOGA

16.4.1 Structure of Trading Agents

The U-Mart system carries out simulation with discrete time steps $t = 1, \dots, t_{\text{end}}$. In period t , each trading agent can observe

- $S(t) = \{s(1), \dots, s(t-1)\}$: spot prices of the stock index up to the previous period $t - 1$,
- $F(t) = \{f(1), \dots, f(t-1)\}$: futures prices in the U-Mart up to the previous period $t - 1$,
- $position(t - 1)$: the position of the agent,
- $cash(t - 1)$: amount of cash possessed by itself, and
- $rest(t)$: remaining time up to the final period.

Observing these variables, each agent must decide his action consisting of

- $p(t)$: limit price of the order,
- $sb(t)$: type of order, i.e., sell or buy,
- $q(t)$: quantity of the order,

for each period t .

Hence, the strategy of the agent can be formalized as the following function F :

$$(p(t), sb(t), q(t)) = \text{Strategy}(S(t), F(t), \text{position}(t-1), \text{cash}(t-1), \text{rest}(t-1)) \quad (16.1)$$

We have constructed agents having the following two structures.

Model 1. This model is a sort of agent having strategies based on technical analysis, i.e., time series prediction of the prices. The agent consists of the following three parts:

Risk Management Part : In the U-Mart, to maintain adequate position to avoid bankruptcy is a basic requirement for program agents. In this model, the agent memorizes the maximum price change max_d for the past n periods,

$$max_d = \max_{\tau=t-n, \dots, t-1} |f(\tau) - f(\tau-1)| \quad (16.2)$$

and obtain a pessimistic estimate of its asset based on the history of past n periods when it keeps the current position as follows

$$\text{cash} - (\text{margin} + max_d \times \text{unit}) \times \text{position} \quad (16.3)$$

where $margin$ is the margin for the contracted orders deposited in the market $unit$ is trading unit. If it gets negative, it means the bankruptcy. Hence, the maximal possible position, say $position^*$, can be estimated as a solution of

$$\text{cash} - (\text{margin} + max_d \times \text{unit}) \times \text{position}^* = 0. \quad (16.4)$$

Trend Prediction Part : With linear regression analysis, both the spot prices $s(t)$ and the futures prices $f(t)$ for the past n periods are fitted as linear functions of period t :

$$\tilde{s}(t) = a_s t + b_s, \quad \tilde{f}(t) = a_f t + b_f$$

Further, we assume that the futures prices $f(t)$ can be explained by linear combination of them

$$\hat{f}(t) = y(t)s(t) + (1 - y(t))f(t) = at + b \quad (16.5)$$

where $y(t) \in [0, 1]$ is the combination weight function depending on period. In the beginning, the futures price f will be explained better by $\tilde{f}(t)$ than $\tilde{s}(t)$, hence small $y(t)$ will be preferred. Closing to the end, to use $s(t)$ will be better, and hence large $y(t)$ will be preferred.

In this model, $y(t)$ is represented by a piece-wise linear function of period as shown in Fig. 16.1, and 9 control points are taken as parameters to be decided.

Order Making Part :

Order is made based on two plans. The first plan is based on the trend of the futures price:

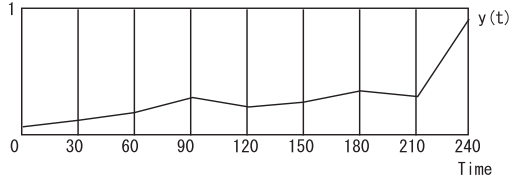


Fig. 16.1. Piece-wise linear representation of $y(t)$.

- If $a > 0$, take sell position.
- If $a < 0$, take buy position.
- Otherwise, take no position.

However, its trend $|a|$ is too strong, it may indicate some instability of the market. Then, to have large position will be dangerous. Considering this risk, the position (normalized by *position'*) $g(a, v)$ to be made is represented as a non-monotonic function of a as follows

$$g(a, v) = \begin{cases} 0 & (a/v \leq -1) \\ 2a/v + 2 & (-1 < a/v \leq -0.5) \\ -2a/v + 2 & (0.5 < a/v \leq 0) \\ 2a/v & (0 < a/v \leq 0.5) \\ -2a/v + 2 & (0.5 < a/v \leq 1) \\ 0 & (1 < a/v) \end{cases} \quad (16.6)$$

where v is a parameter. Let position obtained from Eq. (16.6) be

$$po_1 = position^* \times g(a, v). \quad (16.7)$$

The other plan uses difference between estimated price $\hat{f}(t-1)$ and the actual futures price $f(t-1)$. Position to be taken po_2 is given by

$$po_2 = position^* \times d \times \frac{\hat{f}(t-1) - f(t-1)}{\max_{\tau=1, \dots, t-1} |\hat{f}(\tau) - f(\tau)|} \quad (16.8)$$

where d is a parameter.

These two positions are combined through a weight parameter w_1 . Multiplying a parameter w_2 representing ‘aggressiveness’ of the agent to it, we obtain the position po' to be taken as follows:

$$po' = w_2(w_1 po_1 + (1 - w_1) po_2). \quad (16.9)$$

The difference between po' and the current position

$$q = po' - position \quad (16.10)$$

is taken as the amount of order to achieve po' .

The limit price p is decided by extrapolating the estimated price $\hat{f}(t)$ to the n step future.

Genetic Representation : the above strategy is represented by a chromosome consisting of the following 14 parameters:

- Number of steps $n \in [2, 60]$ used for linear regression analysis.
- Nine parameters to decide function $y(t)$.
- Parameter $v \in [0, 100]$ used in the function g .
- Parameter $d \in [-2, 2]$ used for deciding po_2 .
- Weight parameters w_1 and $w_2 \in [0, 1]$.

Model 2. This model takes a strategy based on arbitrage.

Risk Management Part : As same as the Model 1, maximum possible position, $position^*$ is calculated.

Evaluation of Arbitrage Opportunity : This model decides position to be taken based on the difference between the prices of the spot and the futures:

$$po' = position^* \times y(t) \times \frac{s(t-1) - f(t-1)}{\max_{\tau=t-m, \dots, t-1} |s(\tau) - f(\tau)|}$$

where $0 < y(t) < 1$ is a weight function, and m is the size of the window to evaluate the arbitrage opportunity. As same as Model 1, $y(t)$ is represented by a piece-wise linear function consisting of 8 segments.

Order Making Part : Amount of the order is decided as follows:

$$q = po' - position$$

The limit price is taken as same as the latest spot price.

Genetic Representation : the above strategy is represented by a chromosome consisting of the following 11 parameters:

- Number of steps $n \in [2, 60]$ used for risk management.
- Parameter m used for assessment of arbitrage opportunity.
- Nine parameters to decide function $y(t)$.

16.4.2 Implementation of MOGA

Objective Functions. Performance of a strategy taken by an agent is measured by

$$ProfitRatio \equiv \frac{FinalProperty - InitialProperty}{InitialProperty} \quad (16.11)$$

As for the objective functions representing return and risk, the mean and the variance of the *ProfitRatio* in 30 simulation runs with different spot price series are used. The number of the simulation runs for evaluation of an individual is decided considering the trade-off between stability of the results and computation time through preliminary experiments.

Market Configurations. Each individual in the population is evaluated independently. That is, each individual is put into a separate market with prescribed agents, and its performance in the market is evaluated. Concerning composition of the market, we used two configurations:

Configuration 1 : Market consists of the agent to be evaluated and 20 other agents having rather simple strategies as follows:

Type r : 5 agents that generate orders with random prices around the previous futures price.

Type s : 5 agents that generate orders with random prices around the previous spot price.

Type t : 5 agent that buy futures if the previous price is higher than before, and sell otherwise following the trend of the market.

Type a : 5 agent that buy futures if the previous price is lower than before, and sell otherwise. That is, they are anti-trend traders.

Configuration 2 : The following 9 agents developed in the educational program held in Tokyo Institute of Technology using the U-Mart system are added to Configuration 1:

Agent 1 : An agent that utilizes moving averages of the spot prices with large and small windows.

Agent 2 : An agent that utilizes large and medium window moving averages of both the spot prices and the futures prices.

Agent 3 : An agent that utilizes moving average of the futures prices.

Agent 4 : An agent that utilizes current futures price, the moving averages and their variances.

Agent 5 : An agent that utilizes the differences of the spot price and futures price, and variation of the futures prices.

Agent 6 : An arbitrageur that decides position based on the difference between the prices of spot and futures.

Agent 7 : An agent that decides order based on the difference of the futures price and average price of its contracted orders.

Agent 8 : An agent that utilizes quadratic approximation of the price curve and tries to capture the peak and bottom of the prices so as to decide its order.

Agent 9 : An agent that makes orders using the strategy of ‘Type t’ if the property is larger than the initial value, and ‘Type a’ otherwise.

Algorithm

An algorithm of the MOGA based on the PESA[16.10] is used. Outline of the algorithm is as follows:

1. Generate initial N individuals randomly and evaluate them. Let generation counter $g = 0$.
2. Increment g . If $g = G$, terminate the algorithm. Otherwise choose two parents randomly from the population.

3. Let the counter of generated children $m = 0$.
4. Increment m . If $m = M$ go to Step 2.
5. Generate a child with the UNDX[16.11], and evaluate its objective values.
6. If the child is dominated by one of the individual in the current population, go to Step 4.
7. If all the individuals in the current population is non-dominated, go to Step. 9.
8. Replace a dominated individual with the child, and go to Step. 4.
9. Replace one of the two nearest individuals to the children in Euclidean distance with the children, and go to Step. 4.

Considering available computation time and reliability of the solution, we set $N = 30$, $M = 1$, and the maximum generation $G = 10000$.

Suppression of Non-active Agents. Preliminary experiment with a single objective GA that considers only ‘return’ shows that

1. Initial individual generated randomly usually yields negative returns.
2. Evolution path of strategies shows that return of the agent is gradually improved keeping rather larger risk, and finally positive return is achieved.

In the multi-objective GA, strategy of ‘do nothing’, which yields no return with no risk dominates most of the initial population. Hence, in runs of the naively implemented MOGA, we observed a tendency that population converges to such useless strategies.

To avoid this phenomenon, we evaluate each strategies giving a certain initial position. That is, in 10 runs among 30, the agent starts trade with initial position of 300 unit sell, in 10 runs with 300 unit buy, and in the remaining with no position. The amount of initial position is decided by trial-and-error in the preliminary experiments. Thus, even non-active agents face risk due to the initial position, and therefore it has more selection pressure than in naive implementation.

16.5 Results of Experiments

Results of experiments are shown in Figs. 16.2 (a) ~ (d). These figures show distribution of the objective values of the agents in the market. Good solutions have large values in the return, and small values in the risk, and therefore located in the right lower area of the figures. In these figures, a curve of $y = x^2$ is also plotted. If the profit ratio follows a normal distribution, strategies under this curve yield positive return more than 84% in probability. As for the Fig. 16.2 (d), a curve of $y = x^2/4$, that corresponding 98% positive return is also plotted.

As for Model 1, the MOGA finds good solutions that dominate other simple strategies in Configuration 1. However, in Configuration 2, i.e., in

the market having more sophisticated agents, solutions found by the MOGA located relatively small risk area, and dominated by some of them such as Type s, and Agent 6, which are a sort of arbitrageur. It is interesting that the performances on the simple agents of Type r, s, t and a change largely in Configuration 1 and 2.

As for Model 2, the solution by the MOGA achieves better results. Even in Configuration 2, the obtained strategies dominates most of the other agents, and performances under the 98% curve are achieved. It shows advantage of the arbitrage-based strategies in the futures market.

It should be noted that agents in the population evolve based on evaluation in the separate markets. Evolution of agents in the same market, i.e., co-evolution of strategies is a subject of the future study.

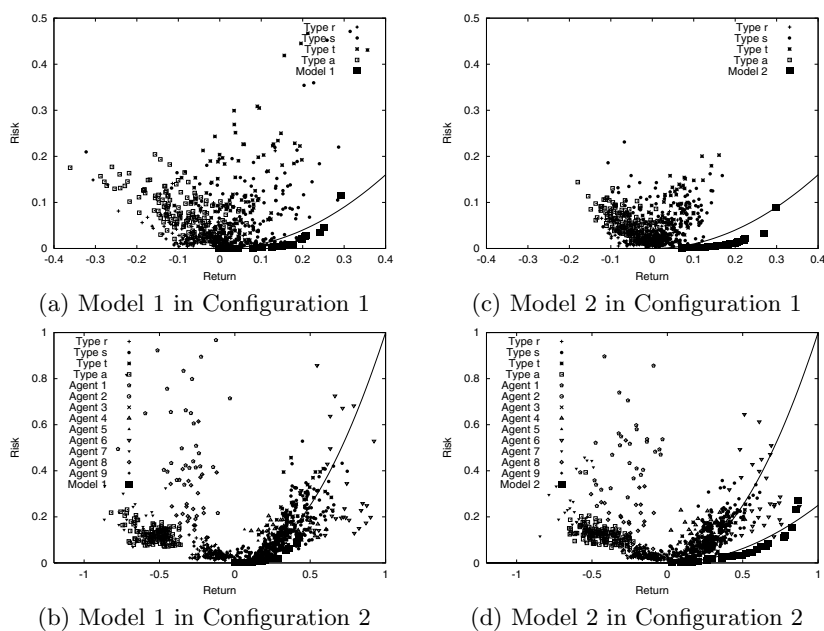


Fig. 16.2. Results of Experiments

16.6 Conclusion

This paper proposes a multi-objective genetic algorithm(MOGA) approach to construction of various trading agents for an artificial market. That is, return and risk are treated objective functions for designing trading agents

using the U-Mart system, an artificial market simulator, as a test bed. Several techniques are also developed to achieve efficient evolution of the agent. Computer simulation shows that various agents having non-dominated trading strategies can be obtained with this approach.

Acknowledgement. The authors express their sincere gratitude to the U-Mart program and its members for valuable suggestions, and Prof. Shigenobu Kobayashi of Tokyo Institute of Technology for valuable comments, and distribution. They also thank to graduate students participated in the educational program using the U-Mart system in the Department of Computational Intelligence and Systems Science of Tokyo Institute of Technology, for let them utilize the trading agents developed in this program.

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17. Agent-Based Simulation for Economic and Environmental Studies

Hideyuki Mizuta¹ and Yoshiki Yamagata²

¹ IBM Tokyo Research Laboratory
Shimotsuruma 1623-14, Yamato, Kanagawa 242-8502, Japan
e28193@jp.ibm.com

² Center for Global Environmental Research
National Institute for Environmental Studies
Onogawa 16-2, Tsukuba, Ibaraki 305-0053, Japan
yamagata@nies.go.jp

The need for new theoretical and experimental approaches to understand dynamic and heterogeneous behavior in complex economic and social systems is increasing. Computational simulation with dynamically interacting heterogeneous agents is expected to be able to reproduce complex phenomena in economics, and helps us to experiment with various controlling methods, to evaluate systematic designs, and to extract the fundamental elements which produce the interesting phenomena in depth analysis. To implement various applications of the agent-based simulation effectively, we have developed a simple framework. We also consider a new application of agent-based simulation for an environmental study and implement a preliminary simulation model of the international greenhouse gas (GHG) emissions trading.

17.1 Introduction

In real economic situations, the dynamic behavior and interactions between people are very complicated and may often seem irrational. Further complicating the situation, the recent progress and popularity of network communication technologies greatly widens the diversity of participants and affects the market mechanism itself, and increases the dynamic fluctuations of economic systems. In the past, traditional economic theories have only considered idealized representative participants in equilibrium states. It is very difficult to analyze dynamically changing situations involving heterogeneous subjects using such static and homogeneous methods. In the last decade, many researchers, including physicists and computer scientists, are starting to apply new approaches to investigate such complex dynamics in their studies of economics. One of these approaches is the agent-based simulation approach.

The term “agent” is often used with different meanings by different researchers (see Fig. 17.1). For example, the word agent may refer to an autonomous graphical user interface with animation, a robot who gathers information from a network, an artificial lifeform, or a distributed application which collaborates with other components over the network. In economics, an agent usually

means an independent economic entity like a household or a firm. However, traditional economic theories usually consider only representative agents in equilibrium states. By using simulation technology, we can endow such economic agents with heterogeneous and dynamic properties. Thus, when we refer to an agent-based simulation, we assume a simulation study of an economic system composed of heterogeneous and dynamic economic entities.

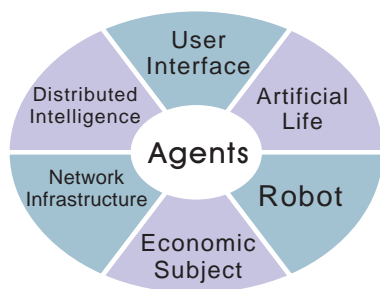


Fig. 17.1. Various Concepts of Agents.

Large-scale agent-based simulations have become possible only relatively recently, with the advent of fast, cheap, and readily available computers. The approach has been championed by physicists using the paradigm of computational statistical physics. De Oliveira et al. [17.1] review several papers from the past few years that exemplify the methodology, especially the work of Levy, Levy, and Solomon [17.2]. This opens the door to the study of the interaction of large numbers of heterogeneous, interacting agents.

In this paper, we will introduce a simple framework for agent-based simulation and three applications: a commodities market, a dynamic online auction, and international greenhouse gas emissions trading.

17.2 Agent-Based Simulation Framework: ASIA

For effective implementations of the agent-based economic and social simulations, we developed a simple framework, Artificial Society with Interacting Agents (ASIA), using Java. This framework provides only very simple and fundamental functionality for social simulations.

Recently, a lot of researchers have begun to investigate agent-based simulations or artificial markets. Also a number of agent systems or frameworks have been proposed to systematically implement models. Many of these frameworks aim at constructing unified structures with object-oriented design methods (For example, [17.3]) and some of them also possess an intelligent collaboration mechanism using the network.

On the other hand, our framework mainly determines the dynamic interactions and trading process as foundations, and leaves the concrete design of

the agents' hierarchy, social structure and individual strategy for the users. We believe that this difference mainly comes from differences in the agent concept as described in the introduction.

We constructed our framework with a layered structure as shown in Fig. 17.2. The agent layer contains a basic agent class and the fundamental environment for the agents. The environment provides the fundamental facilities for agents and users to create agents, to dispose of agents, and to send messages through a MessageManager class.

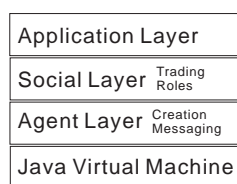


Fig. 17.2. Layer Structure in ASIA.

The MessageManager collects and distributes messages sequentially with its own thread according to the predetermined schedule. Agents also have their own threads to process the distributed messages. Thus, users of the upper layers can construct parallel communication among agents without worry about the message passing mechanism.

The social layer describes the basic role of agents in the society and gives the example of message exchanges for trade. We implemented Central, Participant, and Watcher agents and a simple market process using RFB and BID messages. The Central agent creates, registers and initiates Participant agents and Watcher agents. Users can start, stop, and reset trading through the GUI window provided by the Central agent.

One sample trade procedure can be executed as follows (see Fig. 17.3). To

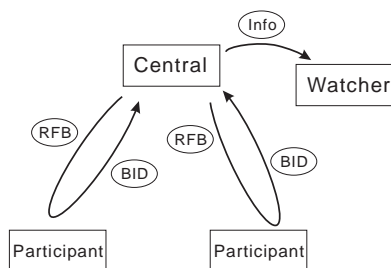


Fig. 17.3. Message Transactions in the Social Layer.

begin a trade, the Central agent sends a Request For Bid (RFB) message to each Participant. Upon receiving a RFB message, a Participant agent replies with a BID message. The Central agent collects all of the BID messages and proceeds to the trade transaction if the users have customized the descendant

appropriately. Finally, each Watcher agent receives information about the trade and report it to the users in the desired format.

The social layer only determines a formal procedure for trading and the users must customize the behavior of agents at the Application layer.

In the following sections, we will give example applications using this framework.

17.3 Market Simulation

The stability of prices in asset markets is clearly a central issue in economics. From a systems point of view markets inevitably entail the feedback of information in the form of price signals, and like all feedback systems may exhibit unstable behavior.

K. Steiglitz and D. Shapiro created the price oscillation and bubbles in a simple commodity market with producer/consumer agents and two types of speculators [17.4]. H. Mizuta, K. Steiglitz and E. Lirov considered the stability in this model with various price signals and found that the anti-weighted average of bid price stabilizes the market dramatically [17.5].

In this section, we reproduce the simulation model described in [17.5] with the ASIA framework.

We use two commodities: *food* and *gold*.

As descendant of the Central agent class, we consider a central auctioneer. There are three kinds of Participant agents. Regular agents produce food or gold and consume food; value traders and trend traders are solely speculators.

One trading period is executed as follows. The auctioneer sends to each agent a Request For Bid (RFB) containing price signals. Consider first the case when the price signal is simply the previous closing price, as in [17.4, 17.6]. Based on this signal, the regular agents decide on their levels of production for that time step and speculators update their estimates. The agents then send bids to sell or buy. Finally, the market treats the submitted bids as a sealed-bid double auction and determines a single price which maximizes the total amount of food to be exchanged.

In each trading period the regular agents can produce either food or gold. They make this production decision to maximize profit, but in a shortsighted way, based only on the current price and their production skills.

Fig. 17.4 shows a screen shot of the system. The PriceAmount Watcher window shows two graphs showing the market clearing price and the trade volume.

In our previous work we showed that the price oscillation with Regular agents is stabilized by introducing different price signals. On the basis of the simulation, we also gave analytical results on the simplified dynamical system with different signals in [17.5].

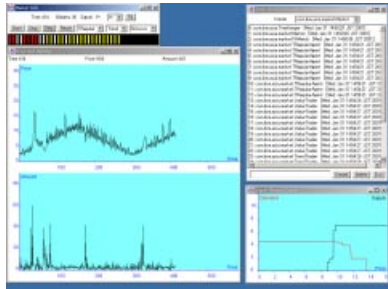


Fig. 17.4. Market Simulation with Agent Framework ASIA, showing a price bubble.

17.4 Dynamic Online Auctions

The use of online auctions is rising at a dramatic rate, and in general many segments of the economy are becoming granulated at a finer and finer scale. Thus, understanding behavior in auctions, and especially the interaction between the design of auctions, agent behavior, and the resulting allocations of goods and money has become increasingly important—first because we may want to design auctions that are as profitable as possible from the sellers' point of view, but also because we may want to bid in auctions, or design computer systems that respond well to the loads that auctions generate. To investigate such dynamic interactions between heterogeneous bidders and the price formulation through successive auctions, H. Mizuta and K. Steiglitz developed an agent-based simulation of dynamic online auctions [17.7]. In this section, we re-implement the auction simulation on the ASIA framework.

The model considers a single auction involving the sale of one item by one seller to one of n bidders, who submit their bids over time in the interval $[0, T)$ to an *auctioneer*, who awards the item to the highest bidder at closing time. A bidder can submit more than one bid during the auction. We define the auctioneer as a Central agent and the bidders as Participant agents.

The starting bid price is fixed at 1, and the duration of the auction is 500 time units.

At the beginning of each auction, each bidder determines his first valuation of the item. At each time period $0 \leq t < T$, each bidder receives the status of the auction, can update his estimation on a fixed schedule or probabilistically, and can submit bids if the conditions for his strategy are satisfied.

We consider two different types of bidders; *early bidders*, who can bid any time during the auction period, update their valuations continuously and compete strongly with each other, and *snipers*, who wait until the last moments to bid. We can briefly characterize the strategy of early bidders as watch/modify/bid, and that of snipers as wait/bid.

An example auction simulated by the complete system is shown in Fig. 17.5.

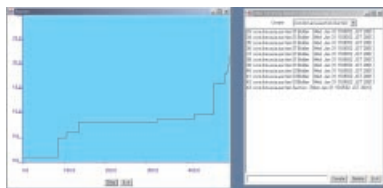


Fig. 17.5. Sample Auction Simulation with Agent Framework ASIA.

17.5 Greenhouse Gas Emissions Trading

In this section, we consider the application of the agent-based simulation for the international greenhouse gas (GHG) emissions trading under the Kyoto Protocol (KP).

To prevent global warming, 160 countries agreed to the KP on limiting GHG emissions at COP3 in 1997. KP sets targets for Annex I countries at assigned reductions below the 1990 levels, with the targets to be met during the commitment period 2008-2012. For example, Japan and the US should reduce 6% and 8% of their emissions, respectively. The KP allows international GHG emission trading, where countries who cannot reach the reduction targets can buy the emissions rights from other countries who can easily satisfy the target. Such a market mechanism is expected to reduce the worldwide cost for GHG reduction because of the large range in the marginal abatement cost curves (MACs) for reducing GHG emissions.

In the previous two sections, we have applied the simulation to relatively traditional market systems, that is, a commodities market and an online auction. Now we will investigate the anticipated properties of an emerging new market through a simulation study. Such a study in advance is important to establish efficient rules, but difficult without simulation.

J. Grütter [17.8] developed the CERT model which calculates the equilibrium price with various options and parameters for MACs. The CERT model treats only one trade in 2010 and each country must achieve the targets in that year. Because this model is implemented with a spreadsheet and macros, it is difficult to expand the model to treat successive trades and to assign different strategies to different countries.

Now we have developed a prototype for GHG emissions trading with the ASIA framework. Because we modeled countries as agents, we can easily modify the behavior of each country and investigate the dynamic interactions between heterogeneous strategies.

The structure of the simulation system is as follows. The COP agent is a descendant of the Central agent and manages the international trading. The Nation agents are descendants of the Participant agent and correspond to countries or groups. In this model, we created 12 Nations; 6 are Annex I countries and 6 are Non Annex I countries who are not assigned targets for reduction. Nations behave autonomously and independently to achieve the

assigned KP targets with minimum costs or to receive maximum profits from the trades.

Fig. 17.6 shows the basic trading procedure through message exchanges. We consider both a static equilibrium market with only one trade in 2010, as was discussed in [17.8], and dynamic market development through the commitment period 2008-2012. In each trading year, a COP agent sends Request for Bid (RFB) messages to all Nations which have an asking price. Upon receiving the RFB message, a Nation agent examines the asking price and his MAC to decide the amount of the domestic reduction. Then he sends back a Bid message to the COP agent which says how much he wants to buy or to sell at the asked price. After repeating this RFB-BID process, the COP model will find the equilibrium price where the demand and the supply balance, and send the Trade message to approve the trades for the year. Thus, the equilibrium price for each year is determined when the MAC functions and the assigned reductions of all of the participants are given.

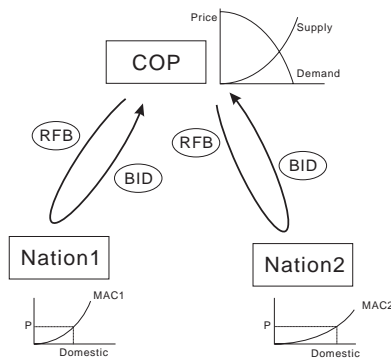


Fig. 17.6. Trading Procedure.

Then we considered multiple trading periods. Nation i divides up the assigned total reduction R_i for each trading period $n = 0, 1, 2, \dots$,

$$\sum_n R_{in} = R_i.$$

As described previously, we can find the equilibrium price P_n^* for each year using a partition of the assigned reduction R_{in} and a MAC function at this time. To consider the dynamics of MAC, we introduce a technology function $t_{in}(p)$ which gives the amount of reduction using the available technology at a given cost p for the Nation i at the year n . Then the MAC is given as the inverse function of the integral of the technology function.

For each year, all countries determine the amount of the domestic reduction with which the values of MAC for all countries agree with one international value, that is, the equilibrium price, to minimize the worldwide reduction cost. Similarly, they try to minimize the total cost over the commitment period by choosing the partition R_{in} ($n = 0, 1, 2, \dots$) for the assigned reduction

which has the smallest variance in the differential coefficient of the total cost for each trading period.

As a simple dynamic process for the reduction technology $t_{in}(p)$, we adopt reusability $0 \leq \alpha \leq 1$ and deflation $0 \leq \gamma \equiv 1/\beta \leq 1$. Once the technology whose cost is lower than the price P^* is used, the reusability of the technology will be restricted with the coefficient α . On the other hand, technical innovations and deflation decreases the cost of each technology. With $\bar{P}_{in} \equiv \max\{\gamma_i^n P_0^*, \gamma_i^{n-1} P_1^*, \dots, \gamma_i P_{n-1}^*\}$, we can obtain the technology function as

$$t_{in}(p) \equiv \begin{cases} \alpha_i \beta_i^n t_{i0}(\beta_i^n p) & p < \bar{P}_{in} \\ \beta_i^n t_{i0}(\beta_i^n p) & \text{otherwise.} \end{cases}$$

We set the initial technology function to be $t_{i0}(p)$ with two coefficients a_i and b_i to reproduce the quadratic MAC function used in the CERT model,

$$t_{i0}(p) \equiv \frac{1}{\sqrt{b_i^2 + 4a_i p}}.$$

In our simulation, we fixed the parameters $\{a_i\}$, $\{b_i\}$ and $\{R_i\}$ for the 12 countries as given in the CERT model and use randomly distributed $\{\alpha_i\}$ and $\{\beta_i\}$. Each Nation agent i determines the initial partition of the reduction $\{R_{in}\}$ and updates the partition after the commitment period so that the variance of the marginal reduction cost decreases.

Fig. 17.7 shows an example of the simulation result. Users can start, stop, and reset the trades and select the trading duration in the upper left window provided by the COP agent. This main window provides information for each Nation's agents, and buttons to open a GUI window for each Nation. Two graphs in the lower left window show the movement of the equilibrium price and the trading amount. There are also graphs for the marginal reduction cost (upper) and the partition of the assigned reduction (lower) of two Nations representing USA (left) and Japan (right). By simulating the dynamic adjustment of the partition, we can see the worldwide cost reduction and the spontaneous selection of strategies. In this particular result, USA chose the late action strategy and Japan chose the early action strategy according to their estimation of rate of the technical innovation and other circumstances.

We can observe changes of the total reduction cost for the entire world and for each country with the view shown in Fig. 17.8. In the beginning of the simulation, all countries fix their partition as the average value through the trading period,

$$R_{in} = R_i/N \text{ (for all } i\text{)}.$$

Then they determine the equilibrium price P_n^* , the domestic reduction $D_{in}(P_n^*)$, and the trading amounts $T_{in}(P_n^*) \equiv R_{in} - D_{in}(P_n^*)$ for each trading period. Simultaneously, they calculate the marginal reduction cost

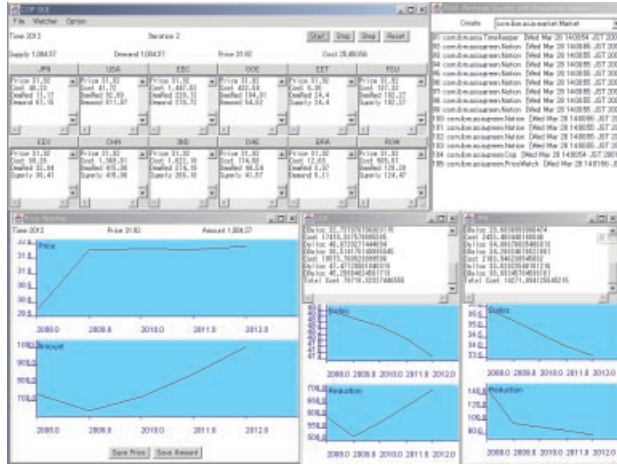


Fig. 17.7. Dynamic GHG Emissions Trading over the commitment period, 2008–2012.

$P_n + T_{in}(P_n^*)/\tau_n^*$ where $\tau_n^* \equiv \sum_j t_{jn}(P_n^*)$. This marginal reduction cost represents the approximate effects of the partition on the total cost for each country. By adjusting the partition after all of the trades so that the marginal reduction costs becomes a constant value over the trading periods, each country expects that the total cost will be optimized. Though each country tries selfishly to decrease only its own cost, the total cost for the world can be reduced via this process as shown in Fig. 17.8.

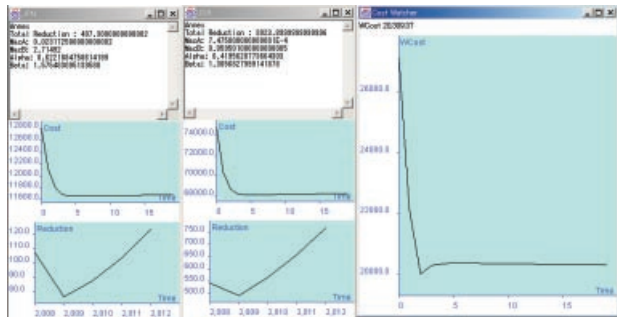


Fig. 17.8. Changes of the total costs via adjustment of the partition.

17.6 Concluding Remarks

We have developed a dynamical simulation for the international GHG emissions trading with our agent-based simulation framework, ASIA. In a simulation study of the international emissions trading, we observed the price formulation for each trading year and the dynamic improvement of strategies which reduce the total cost.

The implementation of various types of the agent-based simulation can be easily done with this framework, since it offers simple and fundamental facilities for agents including messaging, multi-threading, and an example of social negotiation transactions in separate layers. We designed the framework to be very simple following the well-known KISS (Keep it simple, stupid) principle, which enabled us to concentrate on the essential factor in the system and to investigate the dynamics.

At this stage of development, we did not provide intelligence or the network functions for agents which most other frameworks require, because our fundamental concept of an agent does not necessarily require these facilities. However, we do think that a wide range of agent-based simulations can be constructed within this framework. However, we also consider it will be useful for some users if some of these options are available in the higher layer as components they can choose. These optional components for our framework remain for future work. Furthermore, much of the research and analysis required to evaluate GHG emissions trading are also left for the future. We believe that this preliminary work will help in the effective construction of the emerging international market and that such an agent-based approach will have more importance in the near future.

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18. Avatamsaka Game Experiment as a Nonlinear Polya Urn Process

Yuji Aruka

Chuo University, Hachioji, Tokyo 192-0393, JAPAN
aruka@tamacc.chuo-u.ac.jp

We imagine “driving a car” in a busy place. When we wish to enter into a main street from a side road or a parking area along the road, it must be much better for us that someone can give way for us although someone cannot gain any more by giving us whom someone might never meet. This kindness done by someone implies our gain. A symmetrical situation in replacing someone with us holds the same relation. Anybody who gives a kind arrangement to someone, can never be guaranteed to gain from another. If nobody never gave way for someone, the whole welfare on the roads should be extremely worsen. We call such a situation *Avatamsaka Situation* in the sense of the footnote.¹ The gain structure will not essentially depend on the altruistic willingness to cooperate. The model after *synchronizing* our original setting *albeit* a vulgar conversion can be written down as a variant of *coordination games*, although the model can then provide with infinite equilibria in view of individualistic expected utility maximization. A profile of strategic deployments on a set of $\{cooperation, defection\}$ may be argued in a repeated form. Thus one way to look for an eventual end point in our repeated game is to formulate the model in terms of *evolutionary game* of a simultaneous differential equations systems.² On the other hand, this paper will deal with a *stochastic* aspect

¹ **The Original Source:** *Avatamsaka* is a well-known one of the Mahayana Buddhist Sutras. Shigeo Kamata, Professor Emeritus, the University of Tokyo, who is working under the field of Buddhists philosophy, skillfully illustrated the situation of Heaven and Hell in view of *Avatamsaka*. See Kamata [18.5], pp.167-168. Suppose that two men *vis a vis* sat down at the table, across from each other. They however are tied with rope except for one arm only, then given each a too long spoon. Own selves cannot serve them by the use of a too long spoon. There are meals enough for them on the table. If they cooperate in concert to provide each other with meal, they can all be happy. This defines the **Heaven** or **Paradise**. Otherwise, one will be so kind to provide the other with meal but the other might not have a feeling of cooperation. This case however pays the other. This must give rise a feeling of hate for the other. This describes a situation enough to note the **Hell**.

² See Aruka [18.2], pp.10-22 and also “Avatamsaka Game Structure and Experiment on the Web” in Aruka(ed.) [18.3], pp.115-132.

of this evolutionary process. Finally, it is noted that we have *internationally* achieved **Avatamsaka Game Experiment on the Web** by my original program by the use of *File Maker Pro*'s web companion.³

18.1 Characteristics of Avatamsaka Game

18.1.1 Synchronization

We can depict a picture for a vulgar image of *Avatamsaka* situation in terms of *synchronized* payoff structure for playing agents in terms of the two persons game form. On the beginning of our experiment, as we in fact used, we may suggest our subjects to remind of the next scenario:

- Only a piece of block cannot support a dish. If we have two pieces, they can manage to support a dish. Now you join a game.
- Your strategy is restricted either to put a piece beneath on the dish, i.e., *cooperation* or not to put, i.e., *defection*.
- Both players must move simultaneously.
- You must play according to **the next rule**: Both players cannot get a point by the move of “do not put.” You can get a point by the move of “do not put” in case your move consequently never break the dish, but you cannot get a point by the move of “put” when the opponent did not put. You can get a point by the move of “put” when the opponent does put...

Now a bear put a block beneath a dish of glass.
If you remove a block, but a dish did not break down, you can get a point.

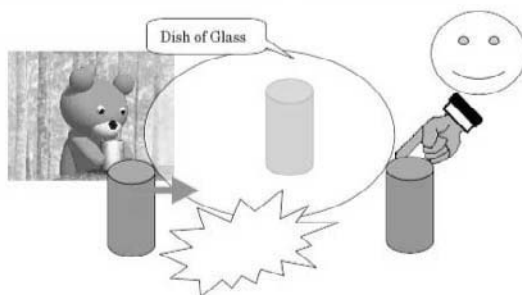


Fig. 18.1. An image of Avatamsaka game

³ We have already had experiments for several times in Chuo University, Japan, J.-W. Goethe(Frankfurt) University, Germany, and Maquette University, USA.

18.1.2 A Two Person Game Form

Now we can give the Heaven and Hell in *Avatamsaka* a numerical example. *Avatamsaka Game* is a kind of *Coordination Game*. You can see this situation from Table 18.1(i), if it is set

$$a = 0, b = 1, c = 0, d = 1 . \tag{18.1}$$

Specifically, see Table 18.1(ii).

Table 18.1. Coordination game and Avatamsaka game

Strategies	Player B	
(i) Coordination game		
Player A	Strategy 1	Strategy 2
Strategy 1	(a, a)	(b, c)
Strategy 2	(c, b)	(d, d)
(ii) Avatamsaka game		
Player A	Defection	Cooperation
Defection	(0, 0)	(1, 0)
Cooperation	(0, 1)	(1, 1)

You can easily check to see one of the Hell situations: if you chose “Cooperation” nevertheless the other “Defection,” you should lose your point. Put another way, you can get gain by choosing Defection, if the other has a kind of altruism. It may be easily verified that this game has infinite equilibria.⁴

⁴ The expected utility of Player A who always uses Strategy D, when Player B uses Strategy D with probability q as well as Strategy C with probability $1 - q$, is

$$E(D, q) = q \cdot 0 + (1 - q) \cdot 1 = 1 - q.$$

For the case Player B always uses Strategy C, their expected utility is

$$E(C, q) = q \cdot 0 + (1 - q) \cdot 1 = 1 - q.$$

There indeed may be infinite solutions q fulfilling

$$E(C, q) = E(D, q).$$

18.1.3 No Complementarities Except for Positive Spillovers to Be Found

In our game we cannot find any complementarities relation as often seen in many coordination games. It is called *a game is complementary*,⁵ if a higher action in view of welfare by Player B increases the marginal return to the action of Player A. The situation can then give a coordination feature. Define, first of all, a marginal return of action switch. If Player A can strictly switches his strategy from Strategy 1 to Strategy 2, when Player B's strategy adopted Strategy 1, the action switch can give the marginal return:

$$\Delta_{A:1to2}^{B:1} = c - a > 0 . \quad (18.2)$$

If Player B adopted Strategy 2, the same switch may, for instance, give the higher marginal return:⁶

$$\Delta_{A:1to2}^{B:2}(A) > \Delta_{A:1to2}^{B:1}(A) . \quad (18.3)$$

Welfare arrangements of choice combination are strictly ordered from higher to lower:

$$(d, d) \succ (a, a) . \quad (18.4)$$

In our *Avatamsaka Game*, there may not be found any complementarities relation.⁷

$$\Delta_{A:1to2}^{B:2}(A) = \Delta_{A:1to2}^{B:1}(A) . \quad (18.5)$$

On the other hand, *Coordination Game* has usually another property called *positive spillovers*. This property implies that each player can increase his own reward as a result of the other's switch of action. In our setting, each player can all increase his reward by the other's switch form Strategy 1 to 2.

$$\Delta_{A:1}^{B:2to1}(A) = b - a > 0, \quad \Delta_{A:2}^{B:2to1}(A) = d - c > 0 . \quad (18.6)$$

There exist *positive spillovers* in *Avatamsaka*:⁸

$$\Delta_{A:1}^{B:1to2}(A) = 1, \quad \Delta_{A:2}^{B:1to2}(A) = 1 . \quad (18.7)$$

Thus it has been seen that there are *no complementarities* but *positive spillovers* in our *Avatamsaka Game*.

⁵ It holds, for instance, if $b < a < d < c$. As for the definitions of *Complementarities* and *Spillovers* see, Cooper [18.4], for example.

⁶ $d - b > c - a > 0$, since $\Delta_{A:1to2}^{B:2} = d - b$.

⁷ $d - b = 1 - 1 = 0$; $c - a = 0 - 0 = 0$.

⁸ $b - a = 1 - 0 = 1$; $d - c = 1 - 0 = 1$.

18.2 Avatamsaka Game Experiment as a Nonlinear Polya Urn Process

18.2.1 The Elementary Polya Process

Underlying an idea of *evolutionary game*, our game experiment has been designed in the following manner. Conventionally, one exercise may be given the participants of experiment, at first. We usually control the league game of a maximum 10 subjects successively for 10 times.⁹ Every subject can have much information of his rivals. He can always *monitor* a current gain of the other players, as well as their names. *Strategic decisions* always depend on the last and the previous results of her self and others reactions. This may mean that the gain distribution will be *path-dependent*.

Now we turn to illustrate an elementary **Polya Urn Process**, which was just introduced into Economics by Brian Arthur, **Snata Fe Institute** and also generalized by him and others,¹⁰ which has been employed to illustrate a *path-dependent process* as well as to confirm an evolutionary end point like industrial locational by spin-off, and a dual autocatalytic chemical reaction, and the like.¹¹

According to Arthur, **Polya Urn Process**, which was formulated by Polya and Eggenbarger [18.6], can be illustrated as follows:

Think of an urn of infinite capacity to which are added balls of two possible colors — red and white, say. Starting with one red and one white ball in the urn, add a ball each time, indefinitely, according to the rule: Choose a ball in the urn at random and replace it: if it is red, add a red; if it is white, add a white. Obviously this process has increments that are path-dependent — at any time the probability that the next ball added is red exactly equals the proportion. We might then ask: does the proportion of red (or white) balls wander indefinitely between zero and one, or does a strong law operate, so that the proportion settles down to a limit, causing a structure to emerge?

Arthur called a limit **proportion** in such a path dependent stochastic process an asymptotic **structure**. As long as the classical proposition is considered, we shall be faced to a limit of proportion, i.e., a simple structure, as proved in Polya [18.7]. In the classical Polya example, we have a restriction such that the probability of adding a ball of type j exactly equals the proportion of type j .

⁹ This experiment demands 45 matches each league game, 450 matches in total, i.e., 45 matches per capita in total.

¹⁰ Yuri M. Ermoliev and Yuri M. Kaniovski, the Glushkov Institute of Cybernetics, Kiev, Ukraine, originally have proved some generalized theorems.

¹¹ See Chapters 3, 7 and 10 in Arthur [18.1].

We apply this kind of Polya stochastic process to our Avatamsaka game experiment to predict an asymptotic structure of the game. In the following we impose the next assumptions for a while.

A1 We suppose there are a *finite* number of players, $2N$, for instance, who join by each pair into our Avatamsaka Game.

A2 We *identify* the ratio of cooperation, or C-ratio for each player *with* the proportion of the total possible gains for each player.¹²

We just notice that we regard a red ball as a gain of Player *A* who loves employing Defection Strategy in our two person game, while a white ball as a gain of Player *B* who loves employing Cooperation Strategy, for instance. Player *A* can then continue to increase his gain if the proportion of his gain is kept higher than Player *B*. It could be possible, provided that Player *B* still clinged to his original policy. The Polya original restriction never allow for Player *B* to change his mind. A *nonlinear* inspection for Players may be taken for account to obtain a more realistic result.¹³

We have usually **10 players** in our game experiment. It may be desired that the Polya urn may contain **ten colors** in order to analyze a **limit proportion** of the times of defection to cooperation of this game.

18.2.2 A Generalized Polya Urn Process

It is quite interesting to learn that Arthur, a pioneer of **Economics of Complexity** has allocated *one third* of the total pages in his reputable book titled *Increasing Returns and Path Dependence in the Economy*(Arthur [18.1]) for generalization of Polya process. That famous term like “lock-in” could not be broadly accepted by specialists if a generalization of Polya process should not be successful. In a generalized version of Polya urn process to allow for a

¹² This assumption seems much *objectionable*. It however is noteworthy to mention that a tendency towards this relationship *sometimes roughly* holds on the average, as shown in our result of experiment of January 24, 2001 in Chuo University: A set of the average proportion of the total possible gains for each player= $\{0.79,0.68,0.60,0.67,0.72,0.74,0.78,0.68,0.73,0.70\}$, a set of the average C-ratios for each player= $\{0.76,0.67,0.53,0.63,0.64,0.76,0.82,0.76,0.73,0.83\}$. The Spearman’s Rank Correlation of the average total gains to the average C-ratios is calculated as 0.627719, while the Kendall’s Rank Correlation is 0.535028. Another reference from experiment of December 12, 2000 in Frankfurt University: A set of the average proportion of gains for each player= $\{0.84,0.70,0.69,0.68,0.82,0.73,0.67,0.72,0.78,0.68\}$, a set of the average C-ratios for each player= $\{0.92,0.89,0.92,0.49,0.8,0.74,0.64,0.51,0.79,0.68\}$. The Spearman’s Rank Correlation of the average total gains to the average C-ratios is calculated as 0.536585, while the Kendall’s Rank Correlation is 0.431818.

¹³ Cooperation *by reinforcement* grows herself, if there is a greater ratio of cooperation. Defection can however grow by exploitng a greater population of cooperation.

more number of agent(color) than two, a random **vector** X whose components are proportions of each agent, instead of a numerical value(ratio), is to be introduced.

In the line of Arhtur, Ermoliev and Kaniovski, we describe a **generalization of path dependent process** in terms of our *repeated game*. Let X_i to be a proportion in the total possible points which Player i gains. The initial total *potential* of gains for each player is defined $2N - 1$.¹⁴ In the next period 2, the total maximal gains will grow by the number of players $2N$. In the period n , therefore, the proportion for Player i at time n will be

$$X_i^n = \frac{b_i^n}{(2N - 1)n} . \quad (18.8)$$

Suppose such a *sample space* that

$$X_i : \Omega \rightarrow [0, 1] , \quad (18.9a)$$

$$\omega \in \Omega \rightarrow X_i(\omega) \in [0, 1] . \quad (18.9b)$$

We can then have a probability $x = X_i(\omega)$ for a sample ω . If a sample implied an experimental result, the sample space Ω could make out a *psychological space* for each agent to give a next move. The probability x may depend on a random variable X_i . If we have $2N$ agents, it then follows a random vector of proportions X^n of period n :

$$X^n = (X_1^n, X_2^n, \dots, X_{2N}^n) \quad (18.10)$$

where it is assumed that each element X_i^n mutually is *independent*, in other words, each agent is *psychologically independent*. Players start at a vector of the initial gains distribution

$$b^1 = (b_1^1, b_2^1, \dots, b_{2N}^1) . \quad (18.11)$$

Let $q_i^n(x)$ define a probability of player i to *earn* a point *by means of Strategy C* in period n .¹⁵ Thus a series of proportions

$$\{X^1, X^2, X^3, \dots, X^n\} . \quad (18.12)$$

will be generated after the iteration of n times.

In the following, q^n behaves as a rule for a *mapping* from X^n to X^{n+1} . Consider a one-dimensional dynamics.

$$q_i(X_i)(\omega) \in [0, 1] , \quad (18.13a)$$

$$q_i(x) : \Omega \rightarrow [0, 1] . \quad (18.13b)$$

If X^n , as a random variable giving a proportion x , appeared at a low level, a value of X^{n+1} might be greater than the previous value of X^n . This case is

¹⁴ It is the case if players all mutually cooperate.

¹⁵ Speaking strictly, probability q may be regarded as an *ex post* probability in a sense of Bayesian.

implied by **A2** that a low level of proportion in gain can induce an increase of the ratio of cooperation in an individual strategy.¹⁶ If q is *nonlinear*, a *nonlinear* dynamics may be generated. See Figure 18.2.

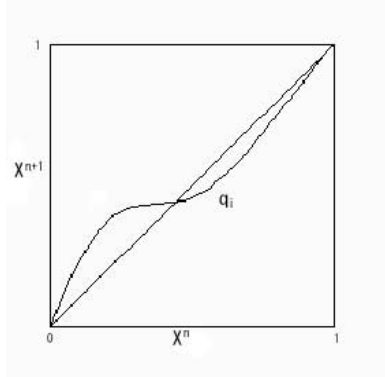


Fig. 18.2. A nonlinear functional form of q

18.2.3 A Nonlinear Polya Process

We have already defined a function q for a $x = X_i(\omega)$, on one hand. Now, on the other hand, we define a function β for the same ω :

$$\beta_i(X_i)(\omega) \in \{0, 1\}, \tag{18.14a}$$

$$\beta_i(x) : \Omega \rightarrow \{0, 1\}. \tag{18.14b}$$

It then follows, if $x = X_i^n(\omega)$,

$$\beta_i^n(x) = 1 \quad \text{with probability given by } q_i^n(x), \tag{18.15a}$$

$$\beta_i^n(x) = 0 \quad \text{with probability given by } 1 - q_i^n(x). \tag{18.15b}$$

Each player might have a maximum gain of $2N - 1$ from the $2N - 1$ matches. Hence **the dynamics** for addition of point by Player i may be written:

$$b_i^{n+1} = b_i^n + (2N - 1)\beta_i^n(x). \tag{18.16}$$

b_i^n then shows an *accumulated* gain at time n through the iteration of game for Player i . Thus **the nonlinear evolution** of the proportion for Player i will, by substitution of X^n , be given in the form of¹⁷

$$X_i^{n+1} = X_i^n + \frac{1}{n+1}(\beta_i^n(x) - X_i^n). \tag{18.17}$$

¹⁶ In a certain circumstance, it may be true.

¹⁷ Deviding the both sides by $(2N - 1)(n + 1)$ and also mutiplying them $\frac{(2N-1)(n+1)}{(2N-1)n}$, it follows the difference equation.

Reformulating this equation in view of

$$\xi_i^n(x) = \frac{1}{n+1}(\beta_i^n(x) - q_i^n(x)), \quad (18.18)$$

we obtain

$$X_i^{n+1} = X_i^n + \frac{1}{n+1}(q_i^n(x) - X_i^n) + \xi_i^n(x). \quad (18.19)$$

Notice that **the conditional expectation** of ξ_i^n is zero.¹⁸ Thus we have reached **the expected motion**:

$$E(X_i^{n+1} | X^n) = X_i^n + \frac{1}{n+1}(q_i^n(x) - X_i^n) \quad (18.20)$$

from which we can easily verify that motion tends to be directed by the term $q_i^n(x) - X_i^n$. Arthur and others call this process *a nonlinear Polya process* when the form of q is *nonlinear*, as indicated in Figure 18.2 in the above.

The above process is just *a martingale*. By a direct application of the theorems of Arthur, Ermoliev and Kaniovski, we could justify a convergence of the C-ratios in the community *not* to the extreme points like 0, 1.

Players shall initially be motivated by the behaviors of the other players. Eventually, however, players' behavior could be independent from the others.

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¹⁸ By the definition of β , it follows that $E(\xi_i(x)) = 0.5 \frac{1}{n+1}(1 - q_i(x)) + 0.5 \frac{1}{n+1}(0 - (1 - q_i(x))) = 0$.

19. Effects of Punishment into Actions in Social Agents

Keji Suzuki

Future University-Hakodate, Kameda-Nakano 116-2, Hakodate City, Hokkaido, 040-8655, JAPAN, E-MAIL:suzukj@fun.ac.jp

This chapter shows the agent based approach to solve the tragedy of the common. The tragedy of the common is known to treat the problem that is how to manage the limited common resource. In the agent-based approach, a meta-agent is introduced to restrict the activity of agents by charging levies. It is supposed that the meta-agent and the agents don't know the payoff function explicitly. Under this setting, the meta-agent try to make levy plan to restrict the agent activity and the agents tries to make the prediction of payoffs for decision making. To create the levy plan and prediction of payoffs, the genetic algorithms are used in each agent. Throughout the experiments, the formation of the levy plan and the prediction of payoffs to avoid the tragedy are shown.

19.1 Introduction

Agent based social behavior simulations are research field that treats complex game situations and examines artificial intelligence [19.1]. Social dilemmas are one of the complex game situations and suite to examine the intelligence of agents. In this paper, the Tragedy of the Common [19.2], which is one of the social dilemmas, is treated in the agent-based simulation. In this game, players use common limited resources to get the reward. If players behave based on the individual rationality, all players will face to tragedies losing higher payoff. To avoid such tragedies, players have to make the relationship between other agents to prevent the selfish behaviors or change the problem structure, for example, changing the payoff functions. The proposed approach is kind of the changing problem structure. That is, the meta-agent is introduced to control the levy charging to the players [19.3]. In addition, it is assumed to all players doesn't know the structure of payoff function explicitly. The assumption can be thought as reflecting a part of complex real situations. Under this assumption, the objective of the simulation is to show the effectiveness between the coevolved levy plan of meta-agent and payoff predictions of agents. In the next section, the problem structure of the tragedy of common is introduced. Then the proposed approach is described.

19.2 The Tragedy of the Common

The tragedy of the common [19.2] is famous game problem as one of the n-persons social dilemmas [19.4]. This game enables for us to analyze the behaviors of players sharing common limited resources. Owing to the common resources are limited, higher activity of agents to get the higher payoff will become to bring lower payoff. The example of the payoff function is shown as follows;

$$Payoff f_i = a^i(16 - a^1 + a^2 + a^3 + a^4) - 2a^i \tag{19.1}$$

where, $Payoff f_i$ is payoff of agent i . a^i represents the degree of activity of agent i . Here, 4 agents participate and 4 degrees of the activity, $a^i \in \{0, 1, 2, 3\}$, is supposed. The payoff function becomes like as Table.19.1.

Table 19.1. Payoff table of the Tragedy of the Common

		Total agent activity expect agent i									
		0	1	2	3	4	5	6	7	8	9
a^i	1	13	12	11	10	9	8	7	6	5	4
	2	24	22	20	18	16	14	12	10	8	6
	3	33	30	27	24	21	18	15	12	9	6

Let's consider the game in which the player decides own activity based on the individual rationality. The game assumes the activity of agents consuming the limited common resources. Therefore, the payoff becomes will decrease when total activities increase. However, the Agent i will increase the activity against any total activity of other agents, because the agent i can increase own payoff until the total activity reaching 11 in the example. Namely, the strategy of higher activity always dominates the strategy of lower activity. Thus all players will decide to increase their activities based on the individual rationality. Thus the decisions based on the rationality will cause the limited common resources being exhausted and all agents will be face to the tragedy. In the example, the tragedy arises when total activities reached 12.

The characteristic of the game is known that no technical solution exists. Therefore, to solve this game, players should change the individual rationalities to other types of rationality or problem structures should be changed to payoff function. One of the objectives of the agent-based simulations is examined what kinds of rationalities and extended problem structures can avoid social dilemmas like as the tragedies. In this paper, the architecture of the proposed agent based simulation is belonging to the extension of the problem structure. Namely, the meta-agent is introduced to prevent the agents based on the individual rationality causing the tragedy. The detail of the proposed approach is described in next section.

19.3 Coevolving Levy Plan and Payoff Prediction

19.3.1 Approach

To solve the social dilemma, especially the game type of the tragedy of the common, it is proposed that coevolution between the levy plan of the meta-agent and the payoff prediction of agents. The approach is belonged to the extension of the problem structure. The charge of the levies can change the obtained payoff of players from the original payoff structure. Therefore even if the players decide their activities based on the individual rationality, suitable levy structure will prevent the activities exhausting the limited common resources. However, the issue of charging the levy approach is remained. That is how to set the suitable levy plan. The issue is connected to the planning policy of levy. In this approach, the individual rationality is employed for planning policy. Namely, the objective of the meta-agent, which will control the levy, is to maximize the incoming levy. While the individual rationality is simple and it isn't required the meta-agent to have specific cooperative rationality, the characteristic of the meta-agent, it is afraid to increase the levy selfishly. To inhibit the selfish behavior of the meta-agent, simple payment rules of the levy from agents to meta-agent is set. The rules are that if the received reward, subtracted payoff from charged levy, become negative, the charged agent doesn't pay the levy to meta-agent. This simple rule and other related rules could be expected to inhibit the selfish behavior of meta-agent.

Related specification of the problem, it is assumed that the meta-agent and the agents doesn't know the payoff structure. The agents are required to decide own activities without the information of other agent's activities. The assumption will reflect the real complex situations. In real complex situations, we may not aware the similarity of the social dilemmas. Therefore, in the simulation model, meta-agent and the agents is expect to acquire the characteristic of the given dilemma structure by trial and error in the iterated games

To acquire the hidden payoff structure, each individual agent tries to construct the prediction of payoff according to its activities. Because the prediction has to be constructed without information of other agent's activities, the implicit synchronization between agents will be required. The implicit synchronization will be arisen from the charging levy by the meta-agent. The implicit synchronization of the agents means that the meta-agents can get stable incoming levies without the prevention of the charging rules. Therefore, the meta-agent also has to construct the suitable levy plan. The suitable levy plan means that the higher levy should be charged to a specific activity and lower levy should be charged to a recommended activity. According to the charged levy plan and their predictions, the agents will select their activity to maximize the rewards based on their individual rationality. Therefore, the meta-agent makes all agents to stably select activities related to higher payoff and charges to them adequate levy without losing incomes. The relation of

the plan of the levy and the prediction of the payoff is expected to avoid the tragedy situations because meta-agent can't get enough levies from the tragedy situations.

To realize the suitable levy plan and synchronized predictions of payoff, the coevolution mechanism is employed as adaptation ability of agents. Each agent and the meta-agent have independent population of chromosomes that represent the plan and predictions. Based on the evaluations function which reflect the individual rationality, the chromosomes are applied the genetic operations. Throughout the experiences of the iterated games, it is expected that the plan of meta-agent and the predictions of the agents will be fixed to avoid the tragedy situation and get higher payoff and levy.

In the following subsections, the details of the proposed methods are explained.

19.3.2 Relation between Levy Plan and Payoff Prediction

The meta-agent has the levy plan for acquiring the incoming levy from the agents. The Levy plan consists of the expected levy values according to the each agent's activities. The all agents have the payoff prediction that consists of the values according to their activities. Both image of the levy plan and the payoff prediction are illustrated in Fig. 19.1. Because the payoff function and other agent's activities are hidden, the levy plan of the meta-agent and the payoff prediction of the agent are limited material for making decision of

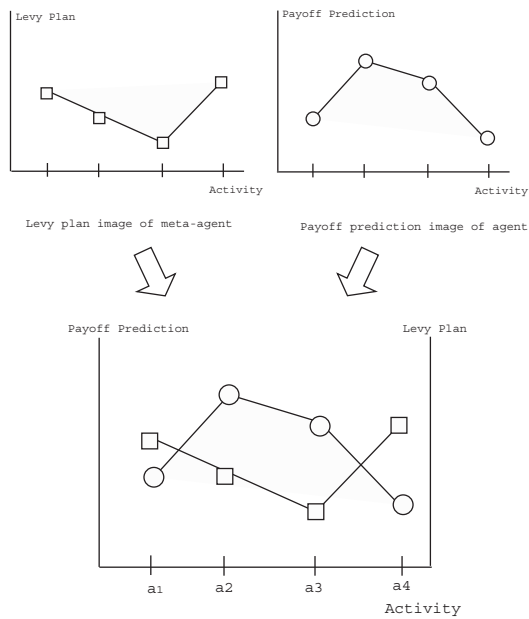


Fig. 19.1. Schematic view of relation between levy plan of meta-agent and payoff prediction of agent.

the agents. The levy plan of the meta-agent is distributed to the agents in each game. The agents combined the accepted levy plan of meta-agent and their payoff prediction for the decision-making.

The process of the decision-making is as follows: first, the agent combines the accepted levy plan and own payoff prediction. From the combined image, the agent, i , decides it's own activity by probabilistic selection. Namely, probability of the activity $a_j^i \in Activity$ is determined from the predicted payoff at activity a_j^i subtracting the value of the levy plan, $Levy_j$. In this probabilistic selection of the activity, the negative probabilistic values are normalized to positive. Therefore, the activities that have higher payoff prediction and lower levy value in the image are relatively selected.

19.3.3 Reward of Agent and Incoming Levy of Meta-agent

According to the decision making of the agents, total activity of all participate agents are determined. From the total activities, payoff value for each agent can be determined. The Fig. 19.2 is shown the evaluation process of reward for the agent. In this figure, the agent, i , is assumed to select activity, $a^i = a_3$, based on the combined image of the payoff prediction and the levy plan. If the relation between the total activities, $\sum_i a^i$ and the activity, a^i become $C2$ in the figure, the reward for the agent is determined from the realized payoff value subtracting the levy value. In this case, the reward value becomes positive. However, if the agent will selects the activity, $a^i = a_1$, the reward value becomes negative. When the reward value becomes negative, the requested levy value can't pay to the meta-agent. Therefore, the reward for the agent is paid only if $Payoff(a^i, Total) > Levy(a^i)$ is satisfied. If the condition is satisfied, the reward value becomes in eq.19.2, otherwise the reward becomes 0.

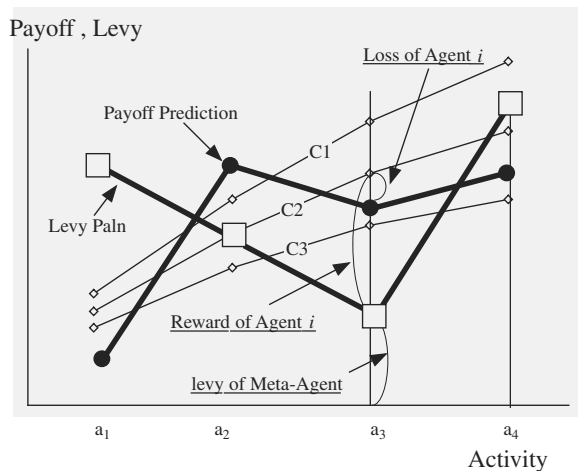


Fig. 19.2. Determination process of reward for agent and incoming levy for meta-agent

$$Reward_i = Payoff(a^i, Total) - Levy(a^i) \quad (19.2)$$

The meta-agent can receive the incoming levy from the agent i , $Levy_{in}(a^i)$, only if $Payoff(a^i, Total) > Levy(a^i)$. Otherwise the incoming levy becomes 0. Namely, the meta-agent can't receive the incoming levy if the requested levy over the realized payoff value. Therefore, the values in the levy plan will be expected to become lower values for getting incoming levies.

19.3.4 Evaluation of Game

To receive enough reward values and incoming levies, suitable levy plan and payoff predictions must be constructed. To adjust the plan and the prediction, the loss values in the game are calculated as evaluation of the game. The value of loss for a game is determined as follows:

$$Loss_i = Payoff_{exp}(a^i) - Reward_i \quad (19.3)$$

$$Loss_{meta} = \sum_i (Levy_{in}(a^i) - Levy(a^i)) \quad (19.4)$$

where, $Loss_i$ is evaluation value of agent i with activity a^i . $Loss_{meta}$ is the summation of the losses related with the activity a^i of the agent i .

According to the received rewards, the incoming levies and the losses, the levy plan and the payoff predictions are adjusted in the coevolution process.

19.3.5 Coevolution of Plan and Predictions

The whole game process is shown in Fig.19.3. Throughout the decision making, the judgment and evaluation, the rewards, incoming levies, and losses are determined. Based on the values, the evaluations of the plan, E_{meta} and predictions, E_i , are calculated as follows:

$$E_i = \frac{Reward_i}{Loss_i} \quad (19.5)$$

$$E_{meta} = \frac{\sum_i Levy_{in}(a^i)}{Loss_{meta}} \quad (19.6)$$

Using the evaluation values, each agent and the meta-agent execute the operations of GA to adjust the plan and predictions. All agents have the population of the chromosomes as the population of GA. The chromosomes represent the plan and predictions. The objective of each GA is to maximize the evaluation value. Namely, it is that maximizing the reward without the loss for the agents and maximizing the incoming levy without the loss for meta-agent. The schematic view of the coevolution process in Fig:19.4

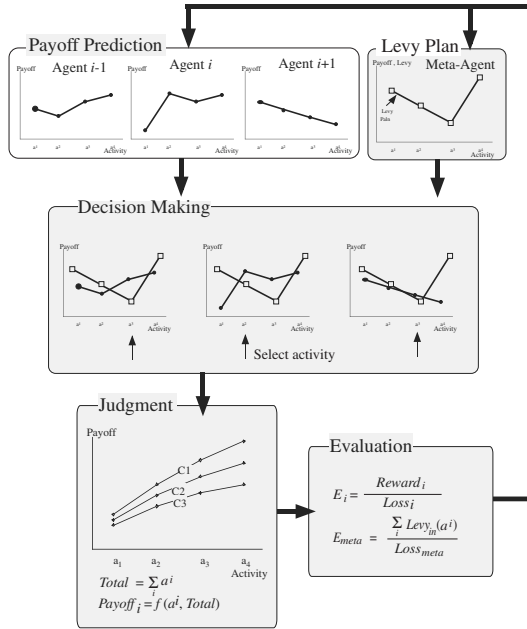


Fig. 19.3. Game process including decision-making, judgment and evaluation with levy plan and payoff prediction.

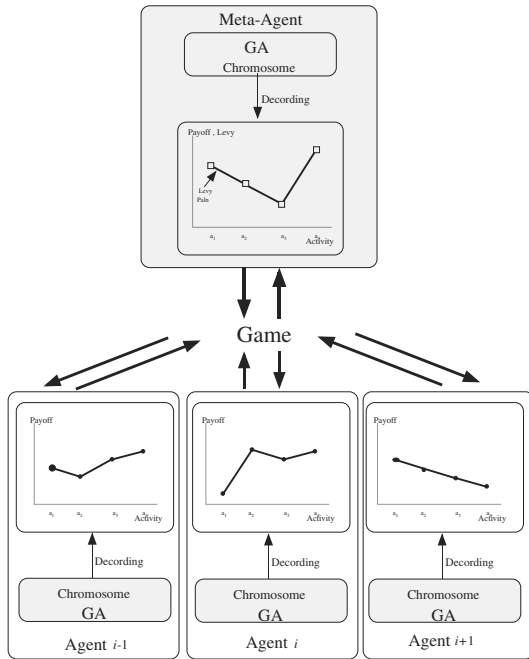


Fig. 19.4. Coevolution between levy plan of meta-agent and predictions of agents.

19.4 Simulation

To confirm the effectiveness of the proposed methods for avoiding the tragedy situation in the social dilemmas, the simulation is executed. The payoff function is set as follows;

$$Payoff f_i = a^i(|A| \times N - \sum_j^N a^j) - 2a^i \quad (19.7)$$

where A denotes the activity, $A = 0, 1, 2, 3, 4$. N is the number of agents. In this simulation, N is set as 4, 6 and 8 to examine the effect of the number of the agents. Each agent and meta-agent has 30 chromosomes. Each chromosome consists of 4 sections for each activity and levy. The length of the section is adjusted to represent the range of payoff function. The decoding of each section is summed up of 1's value. According to the decoded plan and the predictions, the game, the tragedy of the common, is iterated 10 times. The averaged evaluation values are given as fitness of the chromosomes. The crossover and mutation are applied the chromosomes. The crossover rate is 1.0 and the mutation rate is 0.05. Under these parameters, coevolution of meta-agent and the agents are executed until 200 generations.

19.4.1 Game without Meta-agent

To confirm the self-interested rationality of agents, the simulations without the meta-agent are executed. The number of agents is 4 and 6 in these simulations. The results are shown in Fig.19.5 and Fig.19.6. In both figures, the acquired payoff predictions have larger value according to increasing the activity. Thus, the agents tend to select the higher activities in the game that can be seen from the histograms in the figures. Namely, the agents in both cases fail into the tragedy situations.

19.4.2 Simulations with Meta-agents

To control the self-interested agents for avoiding the tragedy situations, the meta-agent is introduced in the simulations. The size of agents are 4, 6, and 8. One of the evolution processes of the meta-agent and 4 agents is shown in Fig.19.7. From this figure, all of the agents and meta-agent can succeed to get enough evaluation.

Fig.19.8 and Fig.19.9 represent the results of the acquired payoff predictions, the levy plan and the histogram of selecting activities in the case of 4 agents and 6 agents. In both cases, the meta-agents set the levy plan of the activity 4 exceeding the payoff prediction value in the activity 4. It means that the meta-agents in both cases prohibit the agents from selecting the activity 4. The effects of the acquired levy plans can be seen in the histograms

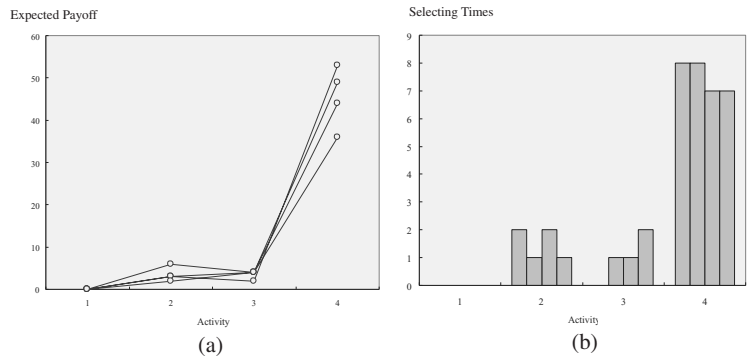


Fig. 19.5a–b. Acquired payoff predictions of 4 agents without meta-agent (a) and histogram of selecting activities of agents (b).

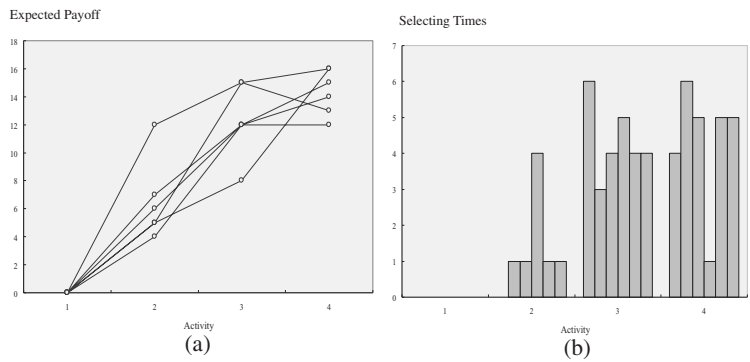


Fig. 19.6a–b. Acquired payoff predictions of 6 agents without meta-agent (a) and histogram of selecting activities of agents (b).

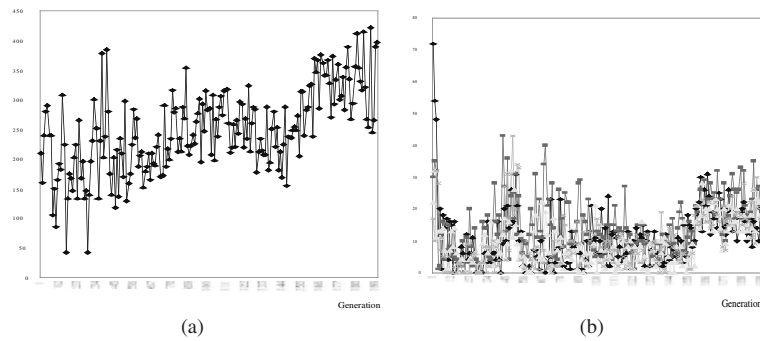


Fig. 19.7a–b. Evolution process of meta-agent (a) and 4 agents (b)

of the selecting activities. The agents didn't select the activity 4. Therefore, the meta-agents succeed to control the agents avoiding the tragedy situations in these cases. The strategy of the meta-agents based on the self-interested rationality evolves to get the higher levies in stable by avoiding the tragedy situation.

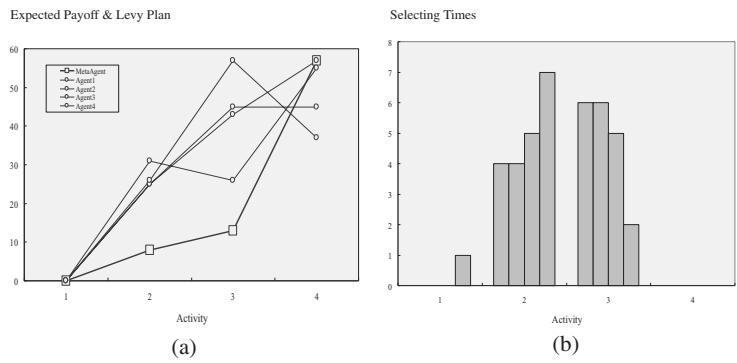


Fig. 19.8a–b. Acquired payoff predictions of 4 agents and Levy plan of meta-agent (a) and histogram of selecting activities of agents (b).

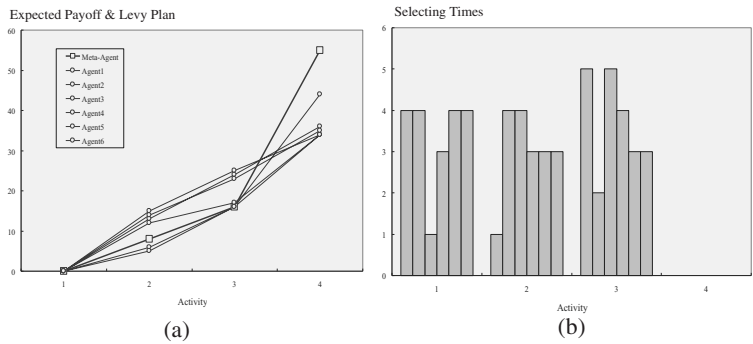


Fig. 19.9a–b. Acquired payoff predictions of 6 agents and Levy plan of meta-agent (a) and histogram of selecting activities of agents (b).

In the above cases, the meta-agents succeed to control the activities of the agents. However, the situation is changed in the case of the number of agents becoming 8. The result of the 8 agents case is shown in Fig.19.10. The acquired levy plan prohibits selecting the activity 3 and some agents prohibit selecting the activity 4. Thus the almost agents can select the activity 4 and they sometimes close to the tragedy situation. That means, the strategy of the

meta-agent is changed in this case. If a few agents select the higher activity and the others select the lower activities, the agents selecting the higher activity will get large payoffs and the meta-agent will get higher incoming levy from these agents. Such situations didn't occur in the previous cases. The meta-agent is aware of these situations in the evolution process. Thus the effective strategy of the meta-agent was changed in this case. Because the some agents prohibit selecting the highest activity, the complete tragedy situation is avoided. However, the self-interested rationality causes to be close the tragedy situations in sometimes.

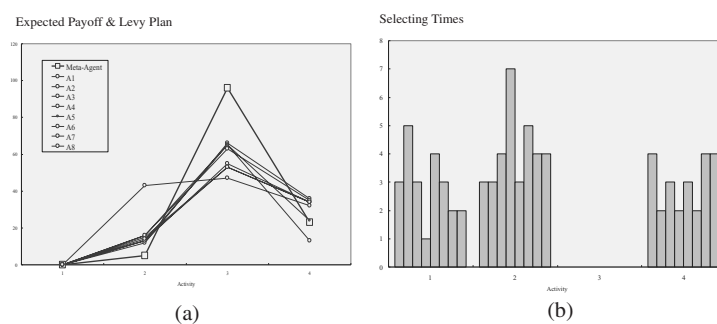


Fig. 19.10a–b. Acquired payoff predictions of 8 agents and Levy plan of meta-agent (a) and histogram of selecting activities of agents (b).

19.5 Conclusion

In this paper, the Tragedy of the Common, which is one of the social dilemmas, is treated in the agent-based simulation. In this game, the meta-agent prepares the levy plan base on the individual rationality. The agents make decisions based on the levy plan and their predictions of payoff. Throughout the coevolution of the plan and predictions in the simulation, the levy plan can prevent to select the activities of the agents toward to the tragedy situation in the case of the group of agents being small. However, the size of the agents becomes large, the strategy of the meta-agent is changed. The complete tragedy situation can be avoided but the agents sometimes close to the tragedy situations. This means it is remaining how to evaluate the closeness to the tragedy situation in the interaction between the meta-agent and agents.

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20. Analysis of Norms Game with Mutual Choice

Tomohisa Yamashita, Hidenori Kawamura, Masahito Yamamoto, and Azuma Ohuchi

Hokkaido University, Kita13 Nishi 8 Kita-ku Sapporo Hokkaido, Japan
{tomohisa,kawamura,masahito,ohuchi}@complex.eng.hokudai.ac.jp

In this paper, our purpose is to represent the establishment of the norm as the indirect sanction of mutual choice that individuals have the rights to refuse interaction. We introduce a mutual choice mechanism in the norms game [20.2, 20.8] instead of a direct penal regulation and then reformulate the norms and metanorms games with mutual choice. As a result, through an agent-based simulation, we confirm that the metanorm for mutual choice supports the establishment of the norm.

20.1 Introduction

The aim of the norms game [20.2, 20.8] is to investigate the emergence and stability of behavioral norms in the context of a game with bounded rationality. The following definition of a norm was formulated by Axelrod: a norm exists in a given social setting to the extent that individuals usually act in a certain way and are often punished when seen not to be acting in this way. In the norms game, an individual player first decides whether to cooperate or defect. The payoff function of this alternative is similar to the N-person Prisoner's Dilemma (N-PD) [20.3, 20.4]. If a player chooses to defect, some of the other players may observe the defection, and these observers may then choose to punish the defector based on the norm "punish those who defect." If the defector is punished, the payoff is a very painful but the punisher has to pay an enforcement cost. The result of this game through an agent-based simulation with evolutionary approach was that the norm collapse but that, if the metanorm is introduced, the norm becomes established. The metanorm was defined as "one must punish those who do not support a norm (those who do not punish a defection)."

The sanction applied in the norms game is that an individual player has the right to punish a defector, or in other words, to directly decrease the payoff of the defector. Do defectors readily agree to such enforcement of a sanction that punishes them and accept a decreased payoff without resistance? For example, a tax delinquent (defector) may not pay a penalty tax if there were no compulsory payment enforced by a centralized direct regulation mechanism. A tax delinquent may also be in arrears in his or her penalty tax. Therefore, a centralized direct regulation mechanism is necessary to compel a tax delinquent to pay the penalty tax. If there is no compelling power, defector would

probably not support penal regulations against defectors. A penal regulation established by an individual would not be enforced. Therefore, it may seem strange to assume that an individual player has the right to punish a defector by directly decreasing the payoff of the defector without the backing of a centralized direct regulation mechanism.

To avoid such a difficulty, we refer to the studies on partner selection in multiple IPD because the concept of partner selection in Prisoner's Dilemma (PD) [20.3] can be considered a kind of sanction. In previous research, many partner selection mechanisms have been purposed: the ostracism option [20.9], the choice and refusal mechanism [20.1, 20.11], the mutual and unilateral choice [20.6], and the option of not game the playing [20.4, 20.6, 20.10, 20.12]. We pick up mutual choice because it does not need the right to directly decrease the payoff of other players. Although this mechanism is used for matching two players, we apply it to an N-person game in the next section. Therefore, under the situation that the payoff without game partners is lower than all payoffs with game partners, the mutual choice mechanism works as an indirect sanction because, if all players only refuse a player, the payoff of the player can be indirectly decreased although no players directly decrease.

In this research, we introduce a mutual choice mechanism into the norms game instead of direct penal regulation and then reformulate the norms game with mutual choice. Furthermore, we introduce a metanorm based on mutual choice. In order to examine the influence of mutual choice, we observe the behaviors of players through an agent-based simulation.

20.2 Mutual Choice in Group Formation

Although previous mutual choice [20.1, 20.7, 20.11] schemes were designed as matching mechanisms where two players play a PD game if both agree to play, we applied this mechanism to an N-person game. Here, we introduce the concept of "group formation [20.5]," which is the process of players choosing each other from within their respective groups and then interacting (playing N-IPD) with only members of the selected player's group. A group is a subset of the overall player set, and each player can join only one group.

The strategy of a player has two dimensions, boldness and vengefulness, in the same way as the original norms game. Let $N = \{1, \dots, i, \dots, n\}$ be the player set, and Boldness B_i be the strategy of player i , which represents the degree of boldness to defect. Vengefulness V_i represents the degree of vengefulness to defection associated with the other players.

20.2.1 Norms Game with Mutual Choice

The norm based direct sanction in the original norms game was changed to a norm based on mutual choice that instructs players to "refuse to interact (play

the N-PD game) with defectors.” Players make decisions on group formation in random order. There are the alternatives of group formation, forming a new group, or joining an existing group. The procedure used for decision making in group formation is as follows.

1) At t -th iteration of group formation, the first player cannot join an existing group but has to form a new group. The players make decisions after the first player chooses one group k out of the group set $G = \{G_1, \dots, G_k, \dots, G_m\}$, where G_k is the set of the players that have already made a decision on group formation. Player i chooses one group based on the expected cooperation with each other player $j (\in N)$, and this is denoted by $\pi_t(i|j)$ [20.1, 20.11]. This expected cooperation is used to determine which group is most tolerable. Given any player i , group k is tolerable for player i in iteration t , only if

$$\frac{\sum^{|G_k|} \pi_t(i|j)}{|G_k|} \geq V_i. \quad (20.1)$$

We define the groups satisfying condition (20.1) as “tolerable groups.” If any groups are tolerable to player i , then player i makes a game offer to group k , whose average expected cooperation for player i is highest.

2) After the group choice of player i , the group k chosen by player i is given an opportunity to refuse or accept the game offer of player i . The players in group k decide by a majority vote whether to refuse or accept the game offer of player i . The player j in group k agrees to accept player i only if $\pi_t(j|i) \geq V_j$. If the majority of players agree to accept player i , group k accepts the game offer of player i and then player i joins group k . Player i is added to the group k as $G_k \cup \{i\}$, which is the new group k .

3) If group k refuses player i , player i make a game offer to group l , whose average expected cooperation for player i is second highest. Player i continues making game offers until a group accepts its game offer or until all tolerable groups refuse its game offer. If player i is refused by all tolerable groups, player i forms a new group $m + 1$. A new group $m + 1$ including only player i is added to group set G , and then group set G is modified as $G = \{G_1, \dots, G_k, \dots, G_m, G_{m+1}\}$.

4) After decision making for group formation, players in groups of more than two players play N-IPD with the players in the same group.

In the initial iteration of group formation, prior to any interaction, all players have the same initial expected cooperation value π_0 for each player. Expected cooperations are updated whenever N-PDs are played. Consider any player in group k , if player j is not in the group k that includes player i in the current iteration t , the expected cooperation value of $\pi_t(i|j)$ is not changed. On the other hand, if player j is in the group k that includes player i , they both play N-IPD in group k . In the N-IPD of group k , player i can observe the other player j 's decision and denote it as $S(i|j)$. If player j cooperates at rate s in all iterations of N-IPD, player i denotes the decision making history of player j as cooperation rate $S(i|j) = s$ ($0 \leq s \leq 1$). Player

i 's expected cooperation value for player j is updated by taking the weighted average over player i 's decision making history with player j ,

$$\pi_{t+1}(i|j) = w\pi_t(i|j) + (1 - w)S(i|j), \quad (20.2)$$

where the memory weight w controls the relative weighting of distance to recent decision making. Players can observe the decisions and update the expected cooperation values of only players in same group.

20.2.2 Metanorms Game with Mutual Choice

The metanorm we adopt is “refuse to interact (play the N-PD game) with those who interact (play) with defectors.” The metanorms game with mutual choice is based on an extension of the norms game with mutual choice.

When player i makes a game offer to group k , the players in group k make decisions on whether to accept or refuse player i . If the majority of players agrees acceptance of player i , the players opposing acceptance of player i consider the players agreeing acceptance of player i as players accepting a defector into the group. We define in group k the players agreeing acceptance of player i as G_k^{agree} and the players opposing acceptance of player i as G_k^{oppose} , where $G_k = G_k^{agree} \cup G_k^{oppose}$ and $G_k^{agree} \cap G_k^{oppose} = \phi$. The players opposing acceptance of player i leave group k and form the new group G_k^{oppose} based on the metanorm. G_k^{oppose} is assigned to G_{m+1} , and then G is modified as $G = \{G_1, \dots, G_k, \dots, G_m, G_{m+1}\}$. Then, player i joins group k ($G_k = G_k^{agree} \cup \{i\}$). If group $m + 1$ includes only player j , player j makes a game offer to its tolerable groups based on above-described process of group formation.

20.3 Simulation Setup

In this paper, because our purpose is to examine the influence of mutual choice on the norms game and the metanorms game, we concentrate on esta-

Table 20.1. Common parameters in the simulations of four cases. $|C_k|$ represents the number of cooperating players in group k .

Number of players	50
Number of generations	10000
Number of mutual choices per generation	200
Number of N-PDs per mutual choice	20
Initial expected cooperation value π_0	1.0
Memory weight w	0.8
Mutation rate	0.01
Payoff function of cooperators in group k	$ C_k / G_k $
Payoff function of defectors in group k	$0.6 + C_k / G_k $
Payoff for lone player P_{alone}	0.01

blishment and maintenance of a norm. We conducted simulations for both the norms game and the metanorms game under two initial conditions. The first condition is that a norm has already been established and that each player is not bold at all, that is, $V_i = 1$ and $B_i = 0$ ($\forall i \in N$). Under this condition, we examine whether it is possible to maintain a norm established by mutual choice. The second condition is that a norm is not established at all and each player is completely bold, that is, $V_i = 0$ and $B_i = 1$ ($\forall i \in N$). Under this condition, we examine whether it is possible to establish a norm by mutual choice.

In our simulations, genetic algorithms are applied to evolve the player's strategies. The two dimensions of a strategy, boldness B_i and vengefulness V_i , are each divided into 32 equal levels, from 0 to 1. Because 32 levels are represented by 5 binary bits, a player's strategy needs a total of 10 bits, 5 bits for boldness B_i and 5 bits for vengefulness V_i . Each simulation is initialized with a population of all players. A simulation consists of a sequence of generations inter-spaced with genetic phases. Each generation consists of an iteration of the norms or metanorms games with mutual choice in which players make, refuse and accept game offers, that is, conduct the group formation and then play N-IPD. At the beginning of the genetic phase, each player's strategy in a population is assigned a fitness equal to its average payoff given per payoff received. A partner for crossover is selected by means of a roulette wheel selection. Uniform crossover is accomplished between the strategies of a player and a partner to obtain a new strategy for one offspring. After that, the strategy of this offspring is subjected to mutation, where each bit is flipped one bit with a certain probability.

It would be interesting to adopt "bandwagon effect [20.5]" using group size to the payoff function of the N-PD game, but our purpose is to examine the influence of the norm and the metanorm. Therefore, we do not adopt bandwagon effect to simplify our model and the payoff function of the N-PD game in each group depends on only the ratio of cooperating and defecting players. The important parameters and the payoff function of the N-PD game are shown in Table. 20.1.

20.4 Simulation

20.4.1 Maintenance of Norm

First, we will explain the maintenance of the norm in the norms and metanorms games with mutual choice. The results of 10 runs are shown in Figs. 20.1 and 20.2. The 10 circles indicate the average boldness and vengefulness of all players after 10000 generations. The typical dynamics of the maintenance of the norm in each game is shown in Figs. 20.3 and 20.4.

In all of the runs shown in Figs. 20.1 and 20.2, there was little boldness and a great deal of vengefulness. The initial condition was $V_i = 1$ and $B_i = 0$

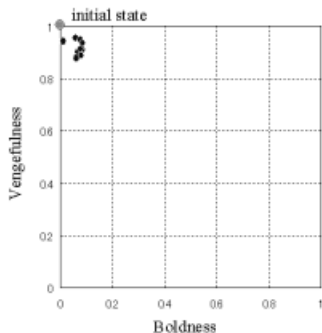


Fig. 20.1. Results of 10 runs of the maintenance of the norm in the norms game with mutual choice: average boldness and vengefulness of all players in 10000 generations under the initial condition $V_i = 1$ and $B_i = 0$ ($\forall i \in N$).

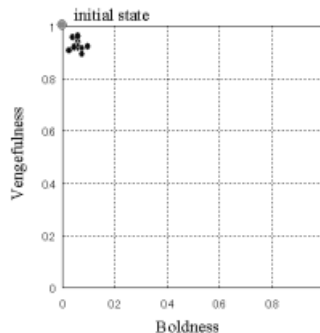


Fig. 20.2. Results of 10 runs of the maintenance of the norm in the metanorms game with mutual choice: average boldness and vengefulness of all players in 10000 generations under the initial condition $V_i = 1$ and $B_i = 0$ ($\forall i \in N$).

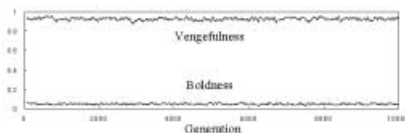


Fig. 20.3. Example of the maintenance of the norm in the norms game with mutual choice: transition of average boldness and vengefulness of all players under the initial condition $V_i = 1$ and $B_i = 0$ ($\forall i \in N$).

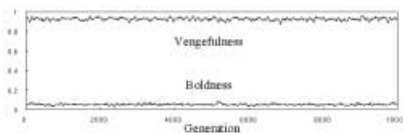


Fig. 20.4. Example of the maintenance of the norm in the metanorms game with mutual choice: transition of average boldness and vengefulness of all players under the initial condition $V_i = 1$ and $B_i = 0$ ($\forall i \in N$).

($\forall i \in N$). Furthermore, in all runs the dynamics of average boldness and vengefulness of a population were similar to the typical dynamics shown in Figs. 20.3 and 20.4. Therefore mutual choice can maintain the norms in both the norms game and the metanorms game because little boldness and a great deal of vengefulness were kept throughout the generations.

In the following explanation we represent a player with a high level of boldness as having B_{high} and a player with a low level of boldness as having B_{low} . In the same way, we represent players as having V_{high} and V_{low} . The reason for the maintenance of the norm is as follows. The mutation of player strategies increases boldness or decreases vengefulness because initial condition there was little boldness and a great deal of vengefulness. The player with boldness increased by mutation, that is, the player with B_{high} , does not join the groups and then acquires a lower payoff because other players

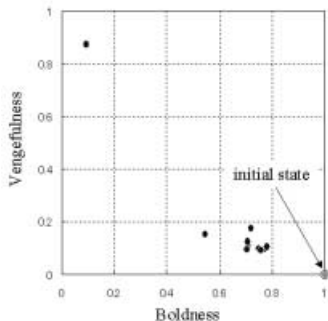


Fig. 20.5. Result of 10 runs of the maintenance of the norm in the norms game with mutual choice: average boldness and vengefulness of all players in 10000 generations under the initial condition $V_i = 1$ and $B_i = 0$ ($\forall i \in N$).

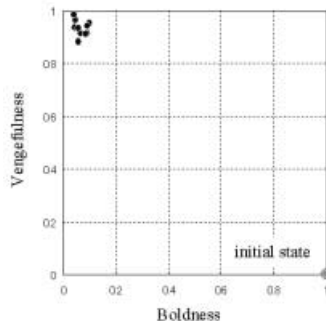


Fig. 20.6. Result of 10 runs of the maintenance of the norm in the metanorms game with mutual choice: average boldness and vengefulness of all players in 10000 generations under the initial condition $V_i = 1$ and $B_i = 0$ ($\forall i \in N$).

with V_{high} refuse the game offers of this player. Consequently, the player with an increased boldness acquires a lower payoff. The player with B_{high} cannot have a freeride on the player with vengefulness decreased by mutation, that is, the player with B_{low} and V_{low} . The reason for this is that, if the player with B_{low} and V_{low} join a group, other players with V_{high} in the same group would refuse the game offer of the player with B_{high} . Even if the player with B_{high} tries to have a freeride on the players with B_{low} and V_{low} , they acquire lower payoffs. As a result, they are not selected in GA and perish. Although in this generation the number of players with B_{high} increases, in the next generation the players with B_{high} cannot have a freeride to acquire more payoffs than the players with V_{high} who cooperate with each other in the group. This is because the players with B_{low} and V_{low} have perished. As a result, the number of players with B_{high} does not increase. Therefore, in the norms and metanorms games with mutual choice, the norm does not collapse and can be maintained.

20.4.2 Establishment of Norm

Next, we explain the establishment of the norm in the norms and metanorms games with mutual choice. The results of 10 runs are shown in Figs. 20.5 and 20.6. The 10 circles indicate the average boldness and vengefulness of all players after 10000 generations. The typical dynamics of the establishment of the norms in each game is shown in Figs. 20.7 and 20.8.

The norms game. In nine of the runs shown in Fig. 20.5, we can observe there a great deal of boldness but little vengefulness. Mutation of player stra-

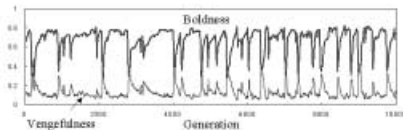


Fig. 20.7. Example of the maintenance of the norm in the norms game with mutual choice: transition of average boldness and vengefulness of all players under the initial condition $V_i = 1$ and $B_i = 0$ ($\forall i \in N$).

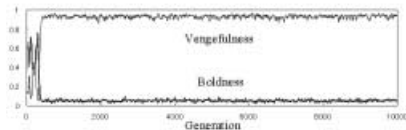


Fig. 20.8. Example of the maintenance of the norm in the metanorms game with mutual choice: transition of average boldness and vengefulness of all players under the initial condition $V_i = 1$ and $B_i = 0$ ($\forall i \in N$).

tegies decreases boldness or increases vengefulness because the initial condition is $V_i = 0$ and $B_i = 1$ ($\forall i \in N$).

At first, we assumed that there was only one player with B_{low} and V_{high} . A player with boldness decreased by mutation, that is, a player with B_{low} , cannot acquire a higher payoff than the players with B_{high} because these players with B_{high} have a freeride on the players with B_{low} . Accordingly, the players with B_{low} do not increase in the next generation. A player with vengefulness increased by mutation, that is, the player with V_{high} , cannot acquire a higher payoff than the players with B_{high} because players with V_{high} do not join a group consisting of players with B_{high} . Therefore, the one player with B_{low} and V_{high} by mutation cannot acquire a higher payoff than the players with B_{high} and V_{low} . Consequently, this player is not selected in GA and perishes.

Next, we assumed that there were plural players with B_{low} and V_{high} . If a group consists of only players with B_{low} and V_{high} , the group refuses the game offers of players with B_{high} . If a group consists of both players with B_{low} and V_{high} and players with B_{low} and V_{low} , it is possible that a player with B_{high} would join this group and have a freeride. The player with B_{high} can join the group because while the players with B_{low} and V_{high} oppose acceptance of its game offer, the players with B_{low} and V_{low} agree it. If the players with B_{low} and V_{low} win the majority vote over the players with B_{low} and V_{high} , the player with B_{high} can join the group. The players with B_{low} cannot acquire higher payoffs than the free-rider. Consequently, they are not selected in GA and perish. Although there are plural players with B_{low} and V_{high} , the players with B_{high} and the players with B_{high} prevent the norm from establishing. The players with B_{high} directly prevent the norm's establishment because they have a freeride on the players with B_{low} and V_{high} . The players with B_{low} and V_{low} indirectly prevent the norm's establishment because they accept game offers from the players with B_{high} who have a freeride on the players with B_{low} . Therefore, in the norms game the norm collapses and does not become established.

In the remaining one run of Fig. 20.6, there was little boldness and a great deal of vengefulness. The reason for the failure to establish the norm was that the player with B_{high} can join the group consisting of both players with B_{low} and V_{high} and players with B_{low} and V_{high} . If there are players with B_{low} and V_{high} but no players with B_{low} and V_{low} , the player with B_{high} cannot join the group and then they defect from each other. As a result, the player with B_{high} acquires a lower payoff than the players with B_{low} and V_{high} who cooperate each other. If the number of players with B_{low} and V_{high} increases and they predominate in the population for few generations before the number of players with B_{low} and V_{low} increases by crossover or mutation, the norm becomes established. Therefore, since the simulation results (Fig. 20.5) show that the norm was established in only one out of ten runs, it is not impossible but difficult to establish a norm in the norm game with mutual choice.

The metanorms game. In all runs shown in Fig. 20.6, there was little boldness and a great deal of vengefulness. In the norms game the establishment of the norm fails because the players with B_{low} and V_{low} accept the game offer of the players with B_{high} . In the metanorms game, if the players with B_{low} and V_{low} agree to accept the game offer of a player with B_{high} and the group as a whole also accepts it, the players with B_{low} and V_{high} leave the group based on the metanorm; they refuse to play the N-PD game with those who play with defectors. The metanorm prevents the player with B_{high} from having a freeride on the players with B_{low} and V_{high} . This is because, if the player with B_{high} joins the group, the players with B_{low} and V_{high} leave the group. As a result, if there are some players with B_{low} and V_{high} , they can form a group without the player with B_{high} . The players with B_{low} and V_{high} can acquire higher payoffs because they cooperate with each other. Throughout this process, the number of players with B_{low} and V_{high} increases and they predominate in the population. Therefore, the norm becomes established.

In the norms or metanorms games with mutual choice, mutual choice can maintain the norm once the norm becomes established just as punishment does in the original games. The results of simulation also indicate the possibility of the maintaining the norm by mutual choice.

In the norms game with mutual choice, the non-vengeful cooperators who cooperate with anyone and accept any game offers indirectly prevent from the establishment of the norm because the non-vengeful cooperators allow defectors to join the group. As a result, the norm collapses and does not become established. Therefore, it is not impossible but difficult to establish the norm by mutual choice the norm collapses and does not become established.

In the metanorms game with mutual choice, although the non-vengeful cooperators accept the game offers of defectors and win the majority vote, the vengeful cooperators who play with neither the defectors nor the non-vengeful cooperators leave the group. Because the vengeful cooperators acquire higher

payoffs more stably than the non-vengeful cooperators and the defectors and also because the number of vengeful cooperators increases in the genetic phase, the norm becomes established. Therefore, the metanorm concerning mutual choice supports the establishment of the norm just as in the original metanorms game.

20.5 Conclusion

In this paper, rather than a direct sanction, we introduced mutual choice as an indirect sanction to the original norms and metanorms games. We proposed a norms game and a metanorms game with mutual choice by changing the original norm and metanorm based on mutual choice. In order to examine the influence of mutual choice, we picked up the maintenance and establishment of the norm. We conducted agent-based simulations under two initial conditions to study the possibility of maintaining and establishing the norm in the norms game and the metanorms game with mutual choice. As a result, we confirmed that mutual choice, as an alternative to the punishment of the original games, can maintain the norm once the norm becomes established. In the norms game with mutual choice it is not impossible but difficult to establish the norm by mutual choice. In the metanorms game with mutual choice the metanorm on mutual choice supports the establishment of the norm just as in the original metanorms game.

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21. Cooperative Co-evolution of Multi-agents

Sung-Bae Cho

Department of Computer Science, Yonsei University
134 Shinchon-dong, Sudaemoon-ku, Seoul 120-749, Korea
sbcho@csai.yonsei.ac.kr

In this paper, we propose a method to obtain strategy coalitions, whose confidences are adjusted by genetic algorithm to improve the generalization ability, in the process of co-evolutionary learning with a social game called Iterated Prisoner's Dilemma (IPD) game. Experimental results show that several better strategies can be obtained through strategy coalition, and evolutionary optimization of the confidence for strategies within coalition improves the generalization ability.

21.1 Introduction

Individual's behaviors in social and economic systems are complex and often difficult to understand. Generally, individual's action is motivated by certain stimulus, thereby the action mechanism can be a kind of dynamic system. So far, there has been much work on the complex phenomena which an individual in the dynamic systems shows from the perspective of game-theory, but it is difficult to deal with more realistic and complex models. Hence, we attempt to understand complex phenomena and systems from the view of evolution in the field of computer science.

Among many economic and mathematical games, Iterated Prisoner's Dilemma (IPD) game is simple but can deal with complex problems such as social and economic phenomena. Axelrod studied on the strategy between humans using IPD game [21.1]. Individuals in social and economic systems show adaptive behavior according to changing environment, because their behavior can be a kind of response to be able to adapt to the stimulus. Especially, immune system in biological systems is representative that shows the stimulus-response well. The immune system can defeat external invaders by gating his opponents to optimal antibody among many antibodies. In the field of co-evolutionary learning, there are many attempts to get better strategies by incorporating this property, and among them fitness sharing is one of the most well-known approaches [21.6].

In this paper, we propose a method to obtain better strategies to adapt to unknown environments, especially which can perform well against the unknown opponents in the IPD game. In order to deal with the problem, we introduce the strategy coalitions, which can be easily recognized in social and economic systems, and obtain them in the process of evolution of strategies. Here, a strategy coalition consists of better strategies extracted from

population. Each strategy in a coalition has the confidence that identifies the proportion of participation in determining the next move of the coalition. In order for the strategies in a coalition to behave adaptively to the changing opponent strategies, we make the confidences for strategies to be changed with his opponent using another evolutionary learning.

Section 2 introduces the IPD game and evolutionary approach to model the game. Section 3 illustrates the evolution of confidences and gating of strategies in coalition to improve the generalization ability, and experimental results are shown in Section 5.

21.2 Evolutionary Approach to IPD Game

One of the most well known games for modeling complex social, economical, and biological systems is the IPD game [21.2]. In the 2-player IPD game, each player can choose one of the two choices, defection (D) or cooperation (C). This game is non-zero-sum and non-cooperative: One player's gain may not be the same as the other player's loss, and there is no communications between the two players. The game is repeated infinitely, and none of the players know when the game is supposed to end.

Table 21.1. Payoff matrix of the 2IPD game. $T > R > P > S$, $2R > T + P$

	Cooperate	Defect
Cooperate	R	S
Defect	T	P

One of the most important issues in evolving game-playing strategies is their representation. There are two different possible representations [21.3, 21.7, 21.8], both of which are lookup tables that give an action for every possible contingency. In this paper, Axelrod [21.1] for the 2IPD game is used.

In this scheme, each genotype is a lookup table that covers every possible history of the last few steps. History in such a game is represented as a binary string of $2l$ bits, where the first l bits represent the player's own previous l actions (most recent to the left, oldest to the right), and the other l bits represent the previous actions of the other player. For example, during a game of 2IPD with a remembered history 2 steps, i.e., $l = 2$, one player might see this history:

$l = 2$: Example history 11 01

The first l bits, 11, means this player has defected (an '1') for both of the previous $l = 2$ steps, cooperated (0) on the most recent step, and defected (1) on the step before, as represented by 01.

For the 2IPD game remembering l previous steps, there are 2^{2l} possible histories. The genotype therefore contains an action (cooperate "0," or defect "1") for each of these possible histories. Therefore, we need at least 2^{2l} bits to represent a strategy. At the beginning of the game, there are no previous l steps of play from which to look up next action, so each genotype should also contain its own extra bits that define the presumed pre-game moves. The total genotype length is therefore $2^{2l} + 2l$ bits.

In the IPD game, each player can be regarded as an agent that has his own strategy, motivated from getting better payoff, and confidence within group. Agents can form a coalition as long as they can get more payoff than other agents or survive for long time. Properties of the agent are shown in Table 21.2 for the IPD game.

Table 21.2. Agent model to play 2IPD game.

Property	Role
ID	unique identifier
History	keep previous moves
Strategy	information for next move
BelongTo	information of coalition
Confidence	proportion of participation in move in coalition
Rank	rank in coalition

21.3 Cooperative Co-evolution of Strategies

21.3.1 Forming Coalition

It is very hard to find one fixed strategy that can play game adaptively against changing opponents in the IPD game. Several methods such as utilizing multiple better strategies such as gating have been widely used to improve generalization ability. Speciated strategies in the IPD game can be obtained by some sophisticated evolution like fitness sharing [21.6].

In this paper, we attempt to obtain the better strategies during the game-playing with the idea of coalition. In social and economic systems, individuals often form a strategy coalition to get better interest than other individuals or survive. In the IPD game, multiple strategies can form coalitions as the

same motivation. We can define the condition that the coalition of strategies can be formed with as follows. The two better strategies belongs to the same coalition,

1. when the game between them brings bad payoff, or
2. when combining them results in good payoff.

In either cases, two strategies must be different because we do not have to duplicate the same strategies in a coalition.

After that, confidence is given to each agent in proportional to his ranking. This confidence has an important role of determining the rate of participation in the move of coalition. Confidence that determines the proportion of participating to the move of coalition is given to each agent. The next move of coalition is determined by the sum of these confidences of agents belongs to it.

21.3.2 Evolving Strategy Coalition

In order to evolve coalition, coalition below the average fitness of agents in the population should be removed and new coalition should be generated from crossover of coalitions in the evolutionary process. In this case, crossover exchanges the agents in coalition. The coalition maintains better agents and removes worse agents from the population. Hence, only strong agents are maintained in the population, and new agents are generated by mixing them within coalition to keep the population from being evolved by weak agents. Figure 21.1 shows the procedure to generate new agents using those in the coalition. Two agents are selected at random among agents within coalition, and their strategies are mixed as the same number of agents in the coalition.

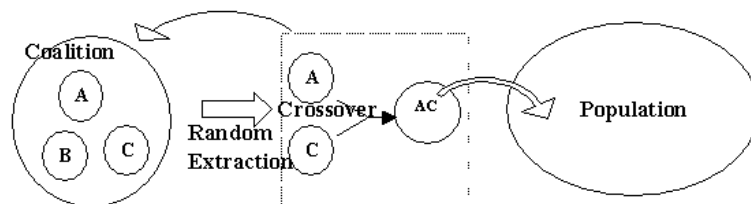


Fig. 21.1. Generation of new agents by mixing agents within coalition to prevent the population from being evolved by weak agents.

21.3.3 Gating Strategies in Coalition

Each agent has a confidence to determine the proportion to the move of coalition. The coalition of fixed confidences would disappear in the course of

evolution, because the coalition would have the difficulty to adapt to the changing opponents. To solve this problem, we adjust the confidences of agents to be able to perform well against changing opponents.

To improve the adaptivity of coalition, techniques such as opponent modeling and gating can be used. Opponent modeling is to model and guess the opponent's strategy, and then change his strategy to be optimal against current opponent. Since this method has difficulty to model opponent's strategy precisely, Darwen and Yao propose a gating method to improve the generalization ability [21.6]. In this method, the optimal strategy in the last population plays against opponent by looking for similar strategies as opponent in the last generation of population.

This paper uses strategy coalition that has history table for his and opponent's moves and use the information to change confidences of strategies according to the change of opponent's action. This has advantage of finding optimal action in the given moves kept in the history. Figure 21.2 shows the modified IPD game structure including the evolution of confidences. The confidences in a coalition are randomly initialized as real numbers from zero to two. The confidence table contains all the confidences of agents for possible combination of history. The training set for adjusting confidences consists of several well known strategies such as TFT, Trigger, CDCD, and so on [21.4, 21.5].

In the evolution, the confidences leading to good result are selected among population of coalitions. Crossover exchanges the confidences between coalitions selected from the population, and mutation changes a specified confidence into a random real number from zero to two.

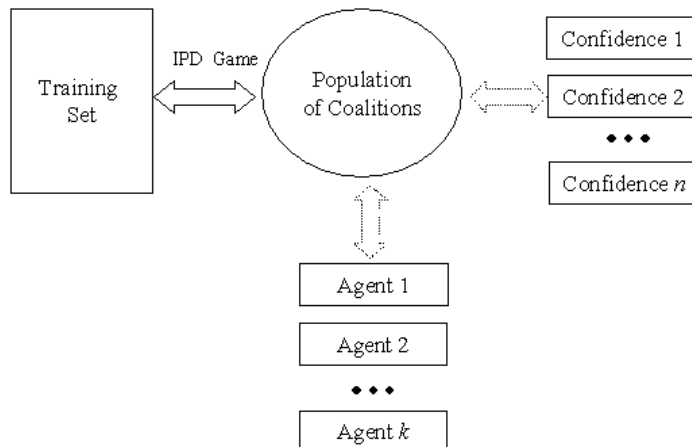


Fig. 21.2. The components of game for evolving the confidences of coalition.

21.4 Experimental Results

In this paper, we have conducted two experiments in 2IPD game with the conventional payoff function. The first one is to obtain strategy coalition using co-evolutionary learning and the second one is to evolve the confidences of obtained coalition through another co-evolutionary learning.

21.4.1 Evolution of Strategy Coalition

To obtain strategy coalition we use the population size of 50, crossover rate of 0.6 and mutation rate of 0.001. One-point crossover with elite preserving strategy is also adopted. History size is 2 and maximum number of agents within a coalition is one third of population. The number of coalitions in the population is restricted under 10.

Figure 21.3 shows the average fitness of coalitions in the evolutionary process. In the beginning of the evolution, average fitness of coalitions is higher than that of agents in the population. However, this difference decreases as time goes by. It does not mean that adaptivity of coalitions decreases, but that agents in the population do not know how to play against the opponents in the beginning of the game, because they are initialized at random. However, as time goes by, many agents learn how to deal with opponent's move. In other words, agents in the population also gradually evolve to adapt for their environment.

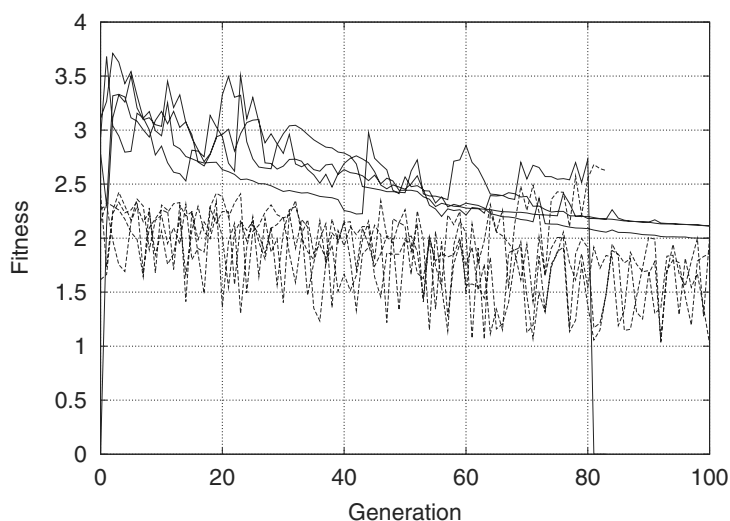


Fig. 21.3. Average fitness of coalitions and agents in the population. Solid lines are for coalitions and dashed lines are for agents.

21.4.2 Gating Strategies

For the experiment of adjusting confidences of agents in coalition, we have the population size of 50 and one-point crossover rate of 0.6. Also, mutation rate is 0.001 and μ - λ selection with elite preserving is used. History size is two and training set consists of well-known seven strategies and a random strategy. Table 21.3 explains the strategies in the training set, and the agents in coalition that have resulted from evolution of strategy coalition are listed in Table 21.4. For the test of generalization ability of evolved coalition, we have selected 30 agents that are top ranked in the population of 300 (as shown in Table 21.5), and conducted ten times runs that evolved coalition plays 2IPD games in round-robin.

Table 21.3. Training set for evolving confidence of coalition.

Strategy	Characteristics
TFT	initially cooperates, and then follows opponent
Trigger	initially cooperates, but once opponent defects continuously defect
TF2T	similar to TFT, but defects for opponent's 2 defection
AllD	always defects
CDCD	cooperates and defects in turn
CCD	cooperates two times and defects
C10DAll	cooperates before 10 rounds and then always defects
Random	moves at random

Table 21.4. An example of agents in coalition.

History	Lookup Table
0 1 0 0	0101110110111101
1 1 1 1	0101101010011111
0 0 0 0	0000101010110101

Table 21.5. 30 opponent strategies that are extracted from the initial population and top ranked in the population.

History	Lookup Table	History	Lookup Table
1000	0111101111101110	1111	1101111001110011
0100	1101111111110011	1100	0101100111010001
1000	1111111000000111	0111	0011111101010010
0111	011111110110111	1111	0111011101010111
1100	0111001101010011	1111	0101101100111100
0001	1011111001011100	0111	1001110101010110
0001	0011010111111110	1101	0001000110011010
1100	0001110110110010	0010	1101110011111101
1000	1101110011011101	1001	1001100101011000
0010	1101101111000110	1000	1101000111101010
1111	1111101100011011	0110	1001011001110110
0110	0111010011011111	1011	0101111101110010
1010	1011010111111100	0001	0011110111011000
1101	1101000101011110	1110	0111010101110001
1100	1101011110111011	1011	0101011111110100

In the experiments, the fitness of coalition increases gradually, and the coalitions show the adaptive behaviors that they cooperate against the conditional cooperators such as TFT, Trigger and TF2T, and defect against defectors. Coalitions defeat or tie with C10Dall or CDCD strategy and always defeat the random strategy. Figures 21.4 is an example result of evolving confidences.

In the test of generalization ability of strategy coalition, the confidences are varied with changing opponents. Experimental results indicate that obtained coalition through evolving confidences of strategies performs better than most of the training set, except AllD and Trigger, in the 2IPD game with the top-ranked 30 opponents in the initial population as shown in Table 21.6.

21.5 Concluding Remarks

We use the strategy coalition to obtain several better strategies in IPD game. Strategy coalition consists of agents and has confidence of each agent. This confidence has an important role in determining the next move of coalition. We have obtained the strategy coalition using co-evolutionary learning, and evolved the confidences to adapt well-known training set using genetic algorithm. In the simulation results, evolving coalitions show the adaptivity that they cooperate in the game with conditional cooperators such as TFT,

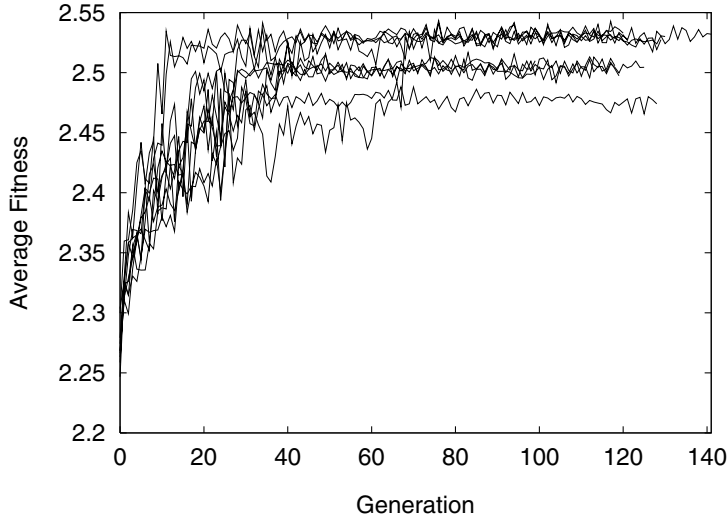


Fig. 21.4. Average fitness of strategy coalition.

Table 21.6. Performance against opponent strategies.

Strategy	Wins	Ties	Avg.	Opp. Avg.
Before	8.64 ± 4.9	6 ± 2.19	1.84 ± 0.28	1.75 ± 0.59
After	18.55 ± 0.5	4 ± 0.63	2.16 ± 0.07	0.92 ± 0.29
TFT	8	0	1.70	1.77
Trigger	30	0	2.13	0.80
TF2T	7	0	1.54	2.40
AllD	30	0	2.17	0.7
CDCD	0	0	1.05	2.75
CCD	0	0	0.91	3.34
C10Dall	27	0	1.97	1.12

Trigger and TF2T, but defect for AllD strategy. Besides, coalition defeats random strategy and defeats or ties with CDCD and C10Dall strategies. In the test of generalization ability with the evolved coalition, we can see that they play better than training strategies except AllD and Trigger in the game with top-ranked 30 strategies of the initial population.

Although we have used the 2-player IPD game in this paper, some of the results we have obtained may be applicable to more complex games. For example, it is interesting to investigate how coalitions could be formed among different countries in the world, how coalitions could be formed among different parties in a country, how coalitions could be formed in the commercial market, etc.

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22. Social Interaction as Knowledge Trading Games

Kazuyo Sato and Akira Namatame

Dept. of Computer Science, National Defense Academy Yokosuka, 239-8686,
JAPAN, {g40045,nama}@nda.ac.jp

In this paper, we propose knowledge transaction as basic constitutes of social interaction. Knowledge transaction among agents with heterogeneous knowledge are formulated as knowledge trading games. Each agent has idiosyncratic utility function defined over his private knowledge and common knowledge shared with the other agents. We consider two types of the utility functions, the convex and concave utility functions. The knowledge transaction are formulated as symmetric and asymmetric coordination games with the combination of the trading agents with those different types of the utility functions. Knowledge transaction in an organization are formulated as the continuous of heterogeneous games. We investigate what characteristics of an organization promote knowledge transaction or discourage sharing common knowledge.

22.1 Introduction

The study of knowledge creation has begun to gain a new wave. Nonaka and his colleagues has developed a new theory of organizational knowledge creation [22.11]. They focus on both explicit knowledge and implicit knowledge. The key to knowledge creation lies in the mobilization and conversion of tacit knowledge. They emphasize knowledge creation in two dimensions, epistemological and ontological knowledge creation. A spiral emerges when the interaction between tacit and explicit knowledge is elevated dynamically from a lower ontological level to higher levels. The core of their theory lies in describing how such a spiral emerge. They present the four modes of knowledge conversion that are created when tacit and explicit knowledge interact with each other. The four modes, which they refer to as socialization, externalization, combination, and internalization, constitute the engine of the entire knowledge creation process. These modes are what the individual experience. They are also the mechanisms by which individual knowledge gets articulated and amplified into and throughout the organization.

The goal of our research is to formalize an economic model of knowledge creation by focusing the quantitative aspects of the value of knowledge. We classify knowledge into two kinds, one is shared knowledge, which is common to each other. This kind of knowledge can be transmitted across agents explicitly. The other type of knowledge is private knowledge. It is personal knowledge embedded in individual experience or knowledge creation. In

this paper, we focus on common knowledge and private knowledge as basic building blocks in a complementary relationship. More importantly, the interaction between these two forms of knowledge is the key dynamics of knowledge creation in the organization of agents. Knowledge creation both at the individual and organizational level is a spiral process in which the above interaction takes place repeatedly as shown in Fig.22.1. In an organization, the individual interacts with other members through knowledge transaction. Knowledge creation takes place at two levels: the individual and the organization, and knowledge creation consists of the forms of knowledge interaction and the levels of knowledge creation.

We consider an organization of agents with heterogeneous knowledge, and knowledge transaction among agents constitute the basic foundation of interactions in an organization. Each member of an organization with private knowledge desires to accumulate both private knowledge and common knowledge. Agents exchange their private knowledge and the transacted knowledge is shared as common knowledge, which also accelerates agents to accumulate their private knowledge. Both private knowledge of each agent and common knowledge in an organization can be accumulated through knowledge transaction. Agents benefit by exchanging their private knowledge if their utility will be increased. At knowledge transaction, each rational agent mutually exchanges his private knowledge so that his utility can be improved. Agents may consider sharing knowledge with others is important for cooperative and joint works, or they put the high value on hiding their private knowledge from other agents. Factors such as the value (worth) of acquiring new knowledge and the cost of sharing knowledge should be considered.

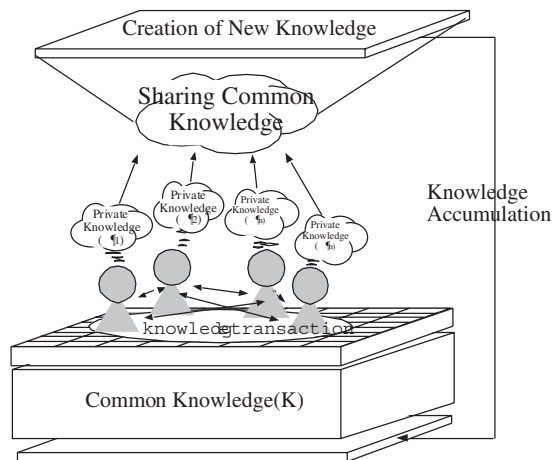


Fig. 22.1. The Process of Knowledge Creation through Knowledge transaction

22.2 Knowledge Transaction as Knowledge Trading Games

As the tasks in an organization grow in complexity, the ways must be found to expand existing knowledge, which increase the opportunities of accessing other knowledge resources [22.2] [22.3] [22.5] [22.10]. Cooperative works, if it is by a team of engineers, or by a group of experts, also require coordination by sharing common knowledge. Many functions and tasks of computers are also carried out through transaction among autonomous agents [22.8] [22.12]. These agents need to have the rights of transparent access knowledge repositories. The knowledge repositories is the accumulated and common knowledge resources and that provides many users in the same organization to explore, to work with, and to discover. To support safe cooperation and sharing of knowledge, while preserving agents' autonomy, agents should negotiate with each other on the access rights and deletion policies on knowledge or when necessary the rights are propagated.

In this section, we formulate knowledge transaction as noncooperative games. We consider an organization of agents $G = \{A_i : 1 \leq i \leq N\}$ with both private knowledge and common knowledge. They transact their valuable private knowledge with other agents, and the transacted knowledge can be shared as common knowledge. Agents may benefit by exchanging their private knowledge if their utility will be increased. Therefore in knowledge transaction, agents mutually trade their private knowledge if and only if their utilities can be improved.

Each agent $A_i \in G$ has the following two trading strategies:

$$\begin{aligned} S_1 &: \text{Trades a piece of his private knowledge} \\ S_2 &: \text{Does not trade} \end{aligned} \tag{22.1}$$

We need to investigate the inductive reasoning process where each agent has different value judgments on trading. Factors such as the value (worth) of knowledge possessed by each agent, the loss for disclosing the knowledge to others should be considered. The associated payoffs of agent A_i when he trades a piece of knowledge are shown as the payoff matrix in Table 22.1. Depending on the payoffs, we can obtain the following four types of the optimal transaction rules agent $A_i \in G$

$$\text{(Case 1)} \quad U_i^1 > U_i^3, \quad U_i^2 > U_i^4 \tag{22.2}$$

In this case, the strategy S_1 dominates the other strategy. The optimal strategy is then to transact his private knowledge without regarding the strategy of his trading partner.

$$\text{(Case 2)} \quad U_i^1 < U_i^3, \quad U_i^2 < U_i^4 \tag{22.3}$$

In this case, the strategy S_2 dominates the other strategy. The optimal strategy is to not to transact without regarding the strategy of his partner.

Table 22.1. The payoff matrix of agent A_i

		Trading partne	
		S_1 (transact)	S_2 (not transact)
Agent A_i	S_1 (transact)	U_i^1	U_i^2
	S_2 (not transact)	U_i^3	U_i^4

$$(Case\ 3) \quad U_i^1 > U_i^3, \quad U_i^2 < U_i^4 \tag{22.4}$$

In this case, the optimal strategy is determined based on the strategy of his partner. If his partner transacts, the optimal strategy become to transacts, and he does not transact, the optimal strategy is not to transact.

$$(Case\ 4) \quad U_i^1 < U_i^3, \quad U_i^2 > U_i^4 \tag{22.5}$$

In this case, the optimal strategy also depends on the other agent. However, if he does transact, the optimal strategy is not to transact, and if he does not transact, the optimal strategy is to transact.

In Case 3 and 4, the optimal strategy is obtained as the function of the strategy of his trading partner as follows: Let denote the possibility of the trading partner is given by p . Then the expected utility of agent A_i when he chooses S_1 or S_2 is given as follows:

$$\begin{aligned} \bar{U}_i(S_1) &= pU_i^1 + (1 - p)U_i^2 \\ \bar{U}_i(S_2) &= pU_i^3 + (1 - p)U_i^4 \end{aligned} \tag{22.6}$$

Then, agent will transact if the following inequality is satisfied:

$$pU_i^1 + (1 - p)U_i^2 \geq pU_i^3 + (1 - p)U_i^4 \quad i = A, B, \tag{22.7}$$

By aggregating the payoffs in Table 1, we define the following parameter termed as threshold associated to each agent $A_i \in G$.

$$\theta_i = (U_i^4 - U_i^2)/(U_i^1 + U_i^4 - U_i^2 - U_i^3) \tag{22.8}$$

Then from the inequality in (22.7), Agent A_i will transacts his knowledge depending on the following two cases:

$$(1) \text{When } U_i^1 + U_i^4 - U_i^2 - U_i^3 > 0 \text{ agent } A_i \text{ transacts if } p > \theta_i \tag{22.9a}$$

$$(2) \text{When } U_i^1 + U_i^4 - U_i^2 - U_i^3 < 0 \text{ agent } A_i \text{ transacts if } p < \theta_i \tag{22.9b}$$

22.3 Knowledge Trading as Symmetric and Asymmetric Coordination Games

In this section, we show knowledge transaction can be formulated as symmetric or asymmetric coordination games, depending on the types of the

utility functions of the two agents. In symmetric coordination games, both agents gain benefit if they select the same strategy, on the other hand, they are better off if they choose different strategies in asymmetric coordination games.

We define the utility function of each agent as the function both his private knowledge and the common knowledge. The utility function of agent A_i is defined as the semi-linear function both his private knowledge Ω_i and the common knowledge K , such as;

$$U_i(\Omega_i, K) = \Omega_i + v_i(K), \quad i = A, B, \quad (22.10)$$

The value $X - v_i(X)$ represents the relative value of agent A_i when he holds knowledge X as private knowledge or the common knowledge. If $X - v_i(X) > 0$, he puts a higher value on knowledge X as private knowledge. If $v_i(X) - X > 0$, he puts a higher value on knowledge X as the common knowledge. We also consider the following three types of the value functions:

Definition: For a pair of knowledge X and Y , ($X \neq Y$)

(1) $v_i(X \vee Y) = v_i(X) + v_i(Y)$, and the value function $v_i(X)$ is linear.

(2) $v_i(X \vee Y) \geq v_i(X) + v_i(Y)$, and the value function $v_i(X)$ is convex.

(3) $v_i(X \vee Y) \leq v_i(X) + v_i(Y)$, and the value function $v_i(X)$ is concave.

If the value function is convex, acquiring common knowledge satisfies the increasing returns. Increased common knowledge brings additional values: acquiring more common knowledge means gaining more experiences of other agents and achieving greater understanding of how to achieve the common tasks. On the other hand, if the value function is concave, acquiring common knowledge satisfies the decreasing returns.

We now consider a knowledge transaction between agent A with his private knowledge X and B with his private knowledge Y . The associated payoffs of both agents in Table 1 are given as follows :

$$\begin{aligned} U_A(S_1, S_1) &= \Omega_A - X + v_A(X \vee Y) \equiv U_A^1 \\ U_A(S_1, S_2) &= \Omega_A - X + v_A(X) \equiv U_A^2 \\ U_A(S_2, S_1) &= \Omega_A + v_A(Y) \equiv U_A^3 \quad U_A(S_2, S_2) = \Omega_A \equiv U_A^4 \end{aligned} \quad (22.11)$$

$$\begin{aligned} U_B(S_1, S_1) &= \Omega_B - Y + v_B(X \vee Y) \equiv U_B^1 \\ U_B(S_2, S_1) &= \Omega_B - Y + v_B(Y) \equiv U_B^2 \\ U_B(S_1, S_2) &= \Omega_B + v_B(X) \equiv U_B^3 \quad U_B(S_2, S_2) = \Omega_B \equiv U_B^4 \end{aligned} \quad (22.12)$$

The above associated payoffs can be interpreted as follows: Once they decide to transact their private knowledge, it is disclosed to the other agent, and it becomes as common knowledge. When both agents decide to trade their private knowledge, the payoffs of both agents are defined as their values of common knowledge minus their values of private knowledge. If agent A does not transact, and agent B transacts, he receives some gain by knowing

new knowledge Y . If agent A trades knowledge X and agent B does not trade, his private knowledge X becomes as common knowledge, and some value is lost. If both agents do not transact, they receive nothing. Knowledge trading have unique features which are not found in the commodity trading. With the knowledge trading, agents do not lose all the value of their traded knowledge. They also receive some gain even if they do not trade if the partner trades. Subtracting U_i^3 from U_i^1 , and U_i^2 from U_i^4 we define the following parameters:

$$\begin{aligned}\alpha_A &\equiv U_A^1 - U_A^3 = -X + v_A(X \vee Y) - v_A(Y) \\ \beta_A &\equiv U_A^4 - U_A^2 = X - v_A(X)\end{aligned}\tag{22.13}$$

$$\begin{aligned}\alpha_B &\equiv U_B^1 - U_B^3 = -Y + v_B(X \vee Y) - v_B(X) \\ \beta_B &\equiv U_B^4 - U_B^2 = Y - v_B(Y)\end{aligned}\tag{22.14}$$

Aggregating the payoffs, we define the following parameters which represent the values of integrating two independent knowledge X and Y .

$$\begin{aligned}\alpha_A + \beta_A &= v_A(X \vee Y) - v_A(X) - v_A(Y) \\ \alpha_B + \beta_B &= v_B(X \vee Y) - v_B(X) - v_B(Y)\end{aligned}\tag{22.15}$$

The parameter β_i , $i = A, B$, represents the difference of the values when they are private knowledge and common knowledge. If $\beta_i > 0$, $i = A, B$, some value of knowledge is lost if it changes from private to common knowledge. If $\beta_i < 0$, $i = A, B$, the value of knowledge increases if it is treated as common knowledge. The parameter $\alpha_i + \beta_i$, $i = A, B$, represents the multiplier effect of knowledge X and Y . If the value functions $v_i(K)$, $i = A, B$, are convex, $\alpha_i + \beta_i$, $i = A, B$, are positive, and if they are concave functions, they are negative.

Depending the signs of the parameters α_i, β_i , $i = A, B$, the knowledge trading games can be classified into the following two types:

(1) Symmetric Coordination Games: The value functions $v_i(K)$, $i = A, B$, are convex

If the value functions $v_i(K)$, $i = A, B$, are convex, then we have $\alpha_i + \beta_i > 0$, $i = A, B$. If both agents have the convex value functions, their value functions defined for common knowledge become to be the increasing return of the scale. In this case, the payoff matrix in Table 22.1, which satisfies the condition of (22.9a), can be transformed the payoff matrix in Table 22.2, which is known as a symmetric coordination game. The coordination game with the payoff matrix of Table 22.2 has two equilibria of the pairs of the pure strategies (S_1, S_1) , (S_2, S_2) , and one equilibrium of the mixed strategy [22.7] [22.8]. Absent an explanation of how agents coordinate their expectations on the multiple equilibrium, they are faced with the possibility that one agent expects one equilibrium and the other agent expects the other, and in this case, the coordination failure may occur by selecting the different strategy.

Table 22.2. The transformed payoff matrix of the knowledge trading
 (i) If $\alpha_i + \beta_i > 0, i = A, B$, the value functions are convex, (ii) If $\alpha_i + \beta_i < 0, i = A, B$, they are concave

		agentB	
		S_1 (trade)	S_2 (no trade)
agebtA	S_1 (trade)	α_B	0
	S_2 (no trade)	0	β_B
		0	β_A

(2) Asymmetric Coordination Games: The value function $v_i(K), i = A, B$, are concave

If the value functions $v_i(K), i = A, B$, are concave, then we have $\alpha_i + \beta_i < 0, i = A, B$. If both agents have the concave value functions, their value functions defined over the common knowledge become to be the decreasing return to the scale. In this case, the payoff matrix in Table 22.2 satisfies the condition of (22.9b), which is known as a asymmetric coordination game. The asymmetric coordination game has two equilibria of the pairs of the strategies $(S_1, S_2), (S_2, S_1)$, and one equilibrium of the mixed strategy. Absent an explanation of how agents coordinate their expectations on the multiple equilibrium, they are faced with the possibility that one agent expects one equilibrium and the other agent expects the other, and in this case, another type of coordination failure may occur by selecting the same strategy.

22.4 Aggregation of Heterogeneous Payoff Matrices

In this section, we consider the knowledge transaction in an organization of agents $G = \{A_i : 1 \leq i \leq N\}$. Each agent A_i has knowledge X_i to be transacted. The payoff matrix of each agent also depends on the knowledge to be transacted. In trading games where there are many agents with heterogeneous knowledge, it is possible to reason about others only in the average. Therefore we assume that each agent reasons the other agents have the knowledge of the same value.

Then each agent has the payoff matrix in Table 22.2 reflecting his judgement on the knowledge trading. We introduce the following parameter, defined as threshold of agent A_i :

$$\theta_i = \beta_i / (\alpha_i + \beta_i) \equiv \{X_i - v_i(X_i)\} / \{v_i(X_i \vee Y) - v_i(X_i) - v_i(Y)\} \tag{22.16}$$

where Y represents knowledge held by the trading partner of agent A_i . The denominator of threshold in (22.16) represents the multiplier effect of sharing knowledge, and the numerator represent the cost of the trading.

From the analysis of the previous section, we can classify the knowledge trading games into the following two types.

(1) The value function $v_i(K)$ is convex.

In this case, agent A_i plays the symmetric coordination games. Let suppose the proportion of agents in G who choose the strategy S_1 is given by $p(0 < p < 1)$. From (22.9a) we have the following optimal transaction rule of agent A_i , which is the function of his threshold θ_i .

$$\begin{aligned} (i) &: \text{He should transact if } p > \theta_i \\ (ii) &: \text{He should not transact if } p < \theta_i \end{aligned} \quad (22.17)$$

(2) The value function $v_i(K)$ is concave.

In this case, agent A_i plays the asymmetric coordination games. From (22.9b) we have the following optimal transaction rule of agent A_i , which the function of his threshold θ_i :

$$\begin{aligned} (i) &: \text{He should transact if } p < \theta_i \\ (ii) &: \text{He should not transact if } if \ p > \theta_i \end{aligned} \quad (22.18)$$

Then, we can classify agents with convex value function into the following three types depending on his threshold θ_i :

(a) $\theta_i \approx 0$ ($\alpha_i \succ \beta_i$): Hard-core of trading

From the optimal transaction rule in (22.17) or (22.18), an agent with low threshold has the strategy S_1 as a dominant strategy. He is willing to disclose his private knowledge without regarding the other agent's strategy. Therefore, we define an agent with low thresholds are a hard-core of trading.

(b) $\theta_i \approx 1$ ($\beta_i \succ \alpha_i$): Hard-core of no trading

An agent with high threshold has the strategy S_2 as a dominant strategy. He does not trade his knowledge without regarding the other agent's strategy. We define an agent with high threshold is a hard-core of no trading.

(c) $0 < \theta_i < 1$: Opportunist

In this case, the optimal strategy depends on his partner's strategy. Therefore we define this type of an agent as an opportunist.

Each agent has idiosyncratic payoff matrix reflecting his own value judgements for knowledge trading. The payoff matrix of Table 22.2 is characterized by threshold defined in (22.16). Therefore, we aggregate of the heterogeneous payoff matrices, one for each member of the organization, and represent as the distribution of threshold. As examples, we consider several threshold distributions in Fig.22.2. An organization with the threshold distribution in Fig.22.2(a) consists of many hard-core of trading with low thresholds. An organization with the threshold distribution in Fig.22.2(b) consists of many hard-core of no trading with high thresholds. An organization with the threshold distribution in Fig.22.2(c) consists of opportunists with intermediate thresholds. An organization with the threshold distribution in Fig.22.2(d) consists of both hard-core of trading and hard-core of no trading.

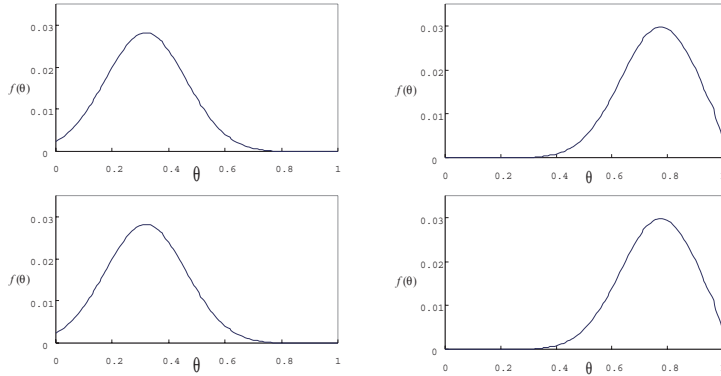


Fig. 22.2a–d. Distribution Functions of Threshold in an Organization (a) An organization of hard-core of trading (b) An organization of hard-core of no trading (c) An organization of opportunistic agents (d) An organization of both hard-core of trading and hard-core of no trading

22.5 The Collective Behavior in Knowledge Transaction

In this section, we investigate the long-run collective transaction in an organization. We provide the evolutionary explanations of studying the collective behaviors motivated by the works in evolutionary games [22.4] [22.9] [22.13]. At any given moment, a small fraction of the organization is exogenously given opportunities to observe the exact distribution in the organization, and take the best response against it.

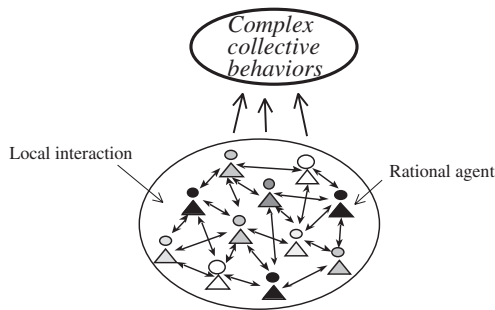


Fig. 22.3. Emergent Collective Behavior in Knowledge transaction

The heterogeneity of the organization G can be represented as the distribution function of their threshold. We denote the number of agents with the

same threshold θ by $n(\theta)$ in G , which is approximated by the continuous function $f(\theta)$, defined as the density function of threshold of G . The proportion of agents whose threshold are less than θ is then given by

$$F(\theta) = \int_{\lambda \leq \theta} f(\lambda) d\lambda \tag{22.19}$$

which is defined as the accumulative distribution function of threshold in G . We characterize the collective behaviors classify into the following two types.

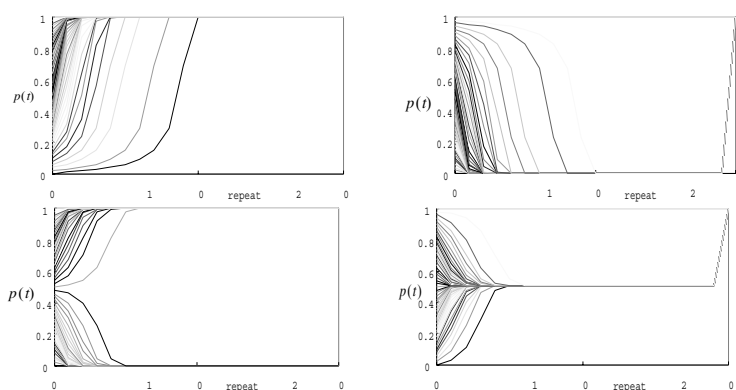


Fig. 22.4a–d. The dynamic process of the collective knowledge transaction (a) An organization of hard-core of trading (b) An organization of hard-core of no trading (c) An organization of opportunistic agents (d) An organization of both hard-core of trading and hard-core of no trading

(1) An organization of agents with convex value functions

In this case, each pair of agents play the symmetric coordination games. We denote the proportion of the trading by the t -th transaction by $p(t)$. Since the optimal transaction rule of an agent with the convex value function is given in (22.17), agents with the threshold satisfying $p(t) \geq \theta_i$ trade at the next time period. The proportion of agents who trade at the next time period $t+1$ is then given by $F(p(t))$. Therefore the proportion of agents who traded can be described by the following dynamics:

$$p(t + 1) = F(p(t)) \tag{22.20}$$

The dynamics is an equilibrium at

$$p^* = F(p^*) \tag{22.21}$$

As specific examples, we consider the knowledge transaction in the organization G with the threshold distribution functions in Fig.22.2.

(Case 1-1) The distribution function of threshold is given in Fig.22.2(a).

The dynamics of the knowledge transaction in this case is shown in Fig.22.4(a). The dynamics has the unique sg equilibrium $p = 1$, where all agents transact.

(Case 1-2) The distribution function of threshold is given in Fig.22.2(b)

The dynamics of the knowledge transaction in this case is shown in Fig.22.4(b). The dynamics has the unique stable equilibrium $p = 0$, where no agent transacts .

(Case 1-3) The distribution function of threshold is given in Fig.22.2(c)

The dynamics of the knowledge transaction in this case is shown in Fig.22.4(c). The dynamics has the two stable equilibria $p = 0$ and $p = 1$. If the initial proportion who transact $p(0)$ is greater than 0.5, then the dynamics converges to $p = 1$, on the other hand, if it is less than 0.5, it converges to $p = 0$.

(Case 1-4) The distribution function of threshold is given in Fig.22.2(d)

The dynamics of the knowledge transaction in this case is shown in Fig.22.4(d). The dynamics has the unique stable equilibrium $p = 0.5$, where a half of the agents transact their knowledge.

(2) An organization of agents with concave value functions

In this case, each pair of agents play the asymmetric coordination games. Let denote the proportion of the agents who transact at the t -th transaction by $p(t)$. Since the optimal transaction rule of an agent with the concave value function is given in (22.18), agents with the threshold satisfying $p(t) \leq \theta$. Agents with thresholds greater than $p(t)$, which is given by $1 - F(p(t))$ will be transacted at the next transaction $t + 1$. Then, the proportion of agents who transact at the next time period is given by the following dynamics:

$$p(t + 1) = 1 - F(p(t)) \tag{22.22}$$

(Case 2-1) The distribution function of threshold is given in Fig.22.2(a)

(Case 2-2) The distribution function of threshold is given in Fig.22.2(b)

(Case 2-3) The distribution function of threshold is given in Fig.22.2(c)

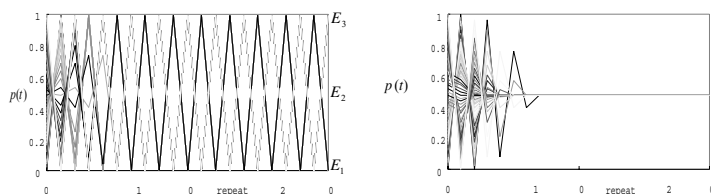


Fig. 22.5a–b.The dynamics knowledge transaction process with cycles (a), and with convergence (b)

With the above three cases, There is no equilibrium, and starting from any initial proportion $p(0)$, the dynamics cycles between the two external points $E_1 : p = 0$ and $E_3 : p = 1$. Once it reaches to one of these extreme points,

it visits each of them alternatively. With this cycles occurs, we have two situations, where all agents trade and no agent trades at the next time, and they repeat this cycle for ever. This phenomenon is known as a coordination failure.

(Case 2-4) The distribution function of threshold is given in Fig.22.2(d)

The dynamics has the unique stable equilibrium $p = 0.5$, where a half of the agents transact their knowledge, which has the same property with symmetric coordination games as shown in Fig.22.5(b).

22.6 Conclusion

The aim of this paper was to formalize an economic model of knowledge creation by focusing the quantitative aspects of the value of knowledge. We classified knowledge into two kinds, shared knowledge and private knowledge. We focused on common knowledge and private knowledge as basic building blocks in an complementary relationship. The knowledge transaction were formulated as non-cooperative games. Different agents necessarily have different payoff structures. We proposed a new type of strategic games, heterogeneous games. We obtained and characterized the optimal transaction rules for each type of the transaction games . Through knowledge transaction, agents, can accumulate organizational knowledge as shared and common knowledge. We characterized the dynamic behavior of knowledge behavior in the long run. We obtained the completely different collective behaviors in the knowledge transaction with an organization of agents with the convex or concave value functions.

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23. World Trade League as a Standard Problem for Multi-agent Economics – Concept and Background

Koichi Kurumatani¹ and Azuma Ohuchi²

¹ Cyber Assist Research Center (CARC), National Institute of Advanced Industrial Science and Technology (AIST Waterfront)
Aomi 2-41-6, Koto, Tokyo, 135-0064, Japan
kurumatani@w-econ.org

² Graduate School of Engineering, Hokkaido University
N13, W8 Kita-ku, Sapporo, 060-8628, Japan
ohuchi@complex.eng.hokudai.ac.jp

We propose a framework called “World Trade League,” which is expected to become a standard problem in multi-agent economics. The first purpose of World Trade League is to propose a network game in the context of economic and social systems. Such a game in World Trade League is executed by several players (countries), where each of country consists of heterogeneous agents such as product makers, service suppliers, financial companies, government, and so on. A player (country) participating in the game is evaluated according to its contribution to development of the international economic system and environment protection, in addition to the development of its own country. The second purpose of World Trade League is to provide a standard problem for pure multi-agent simulations in economic context which many researchers can commonly analyze. The software to execute World Trade League is supplied by *X-Economy* System, where *X-SS* protocol is used for the common communication protocol among agents.

23.1 Introduction

Multi-agent approaches have been now the focus of researchers in modeling and analysis of economic systems in contrast with conventional economic approaches such as equilibrium theory and dynamical systems. Many researchers, however, model and analyze their own economic problems and seem to lack of sharing simulation results and computational techniques.

In such a context, we propose a framework called “World Trade League” [23.1], which is expected to become a standard problem in multi-agent economics. We have mainly two purposes to propose a standard problem. The first one is to propose a network game which is executed by several players connected via networks. Each player represents a country, where each country consists of heterogeneous agents such as product makers, service suppliers, households, financial companies, central bank, government, and so on.

A player (country) participating in the game is evaluated according to its contribution to development of the international economic system and environment protection, in addition to the development of its own country. This regulation is designed to make the game in cooperative and ecology-minded atmosphere rather than selfish competition in international economic systems.

The second purpose is to provide a standard problem for pure multi-agent simulations in economic context where many researchers can commonly analyze the problem and share the simulation results and techniques. For both of the two purposes, the software to execute World Trade League will be supplied as common library *X-Economy* System [23.2, 23.3], where *X-SS* protocol [23.4] is used for the common communication protocol among agents. We design the computational framework to include other applications, such as education, training, entertainment, economic experiment, and so on.

In this paper, we describe the concept and background of World Trade League, with the basic design of network games, simulation frameworks, and computational libraries and communication protocols.

23.2 Concept of World Trade League

World Trade League is a game where each player prepares a country as a multi-agent system consisting of economic agents such as agriculture, manufacturing, distribution, finance, government, and so on [23.1]. Although World Trade League can provide several types of games by changing the configurations and regulations of the system, we explain a full set of the game in the rest of this paper. An agent in a country should behave as follows.

- It collects public information which is open to any agent.
- It does decision-making of what to do now (or do nothing), and it selects one of the options which is available now.

These two parts are essential for agent design and implementation. In addition to them, the following regulations exist.

- Agents in a country should behave independently, i.e., a country has no centralized control system. In order to achieve this restriction, communication among agents even in a country is open to public. Indirect controls are possible by such communication.
- An agent in a county can make international trades with agents in other countries. This is done based on mutual agreement between two agents.

It is a game where heterogeneous agents in several countries collect information, manufacture goods, make international trades, exchange currency, and compete with other countries in order to achieve its own economic development and international collaboration with protecting natural environment (Fig. 23.1).

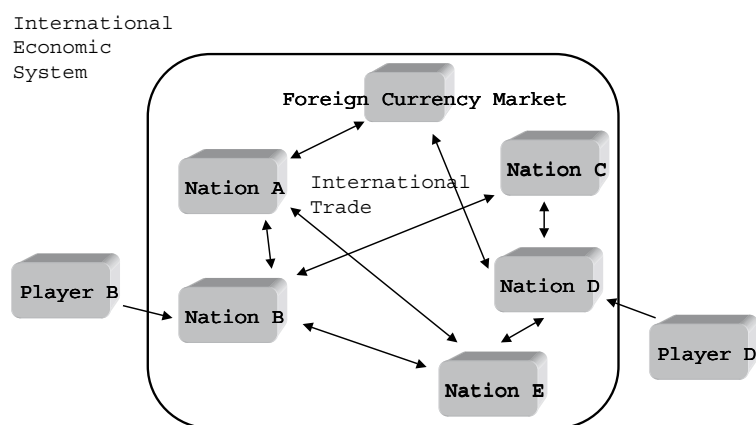


Fig. 23.1. Concept of World Trade League.

23.3 Elements of World Trade League

23.3.1 Behavior Options of Agents and Market Structure

Agents which constitute a country have the following behavior options.

- A) Manufacturing and Service Agents
To plan the amount of goods/services production and to execute it, i.e., to borrow funds from bank, issue stock and bonds, purchase of material, invest in plant and equipment, hire labor power, produce, and sell product.
- B) Distribution Agent
To carry goods and human.
- C) Bank Agent
To loan funds to other agents after determining how much funds it loan to a specific agent. To collect deposits from other agents. To make trades in financial markets.
- D) Central Bank Agent
To decide interest rate and to loan funds to banks. To make trades in markets.
- E) Government Agent
To collect tax and distribute subsidy. To issue national bonds.

F) Natural Resource Agent

This is a special agent to represent natural resources and degree of environmental pollution in a country. It is a passive agent and it does no active decision-making.

In addition to agents, markets are prepared in the system. A market provides a place where a specific goods, funds, capitals, labor powers are traded by agents in the whole system. One market is prepared in the whole system according to one specific object to be traded, i.e., food material, food, industry material, industry goods, labor power, services, national bonds, bonds, stock, and so on.

23.3.2 Game Settings and Complexity

In order to control the complexity of games played in World Trade League, we can make game settings in several ways. In World Trade League, the following ways are prepared to modify the complexity of games.

A) Degree of Economic Evolution

Complexity of games can be modified according to the degree of historical economic evolution as follows.

1. Medieval Stage: Currency exists, but no financial system like money loan exists.
2. Modern Stage: Indirect financial system, i.e., bank loan and national bond exist.
3. Contemporary Stage: Direct financial system, i.e., stock and company bond exist.

B) The Number of Agents in a Specific Agent Type

Complexity depends on the number of agents in a specific agent type. At the starting point, we use only one agent in a specific agent type in a country.

C) The Number of Countries

The number of countries (nations) participating in the game greatly influences the complexity of the game. If the number is one, the game becomes a self-contained game, i.e., an economic simulation of a country. The more nations participate in the game, the more complicated the game becomes. At the starting point, we assume that from two to five nations simultaneously participate in the game.

D) Symmetric or Asymmetric Game

1. Symmetric Game: All nations are given the same initial condition at the starting of the game.
2. Asymmetric Game: The initial conditions of nations are different. By playing games several times with changing the role of nations, the overall condition for each nation can be made equal.

23.3.3 Evaluation Function of Players

Unlike games proposed in previous multi-agent researches, several types of evaluation functions are prepared in World Trade League, i.e., we can run games or simulate economic systems in several types of boundary conditions. Players are evaluated by a single or a combination of the functions, e.g., the average of functions. Each of the function represents a certain aspect of the target economic system, e.g.:

- A) Economic Development of the Country
It represents competitiveness of the world economic system.
- B) Imbalance of Economic Development among Countries
It represents cooperativeness of the world economic system.
- C) Stableness of the World Economic System
It represents stableness of the whole system, in order to avoid sudden changes in a country or in the whole system.
- D) Degree of Environment Protection
It represents ecological coexistence of a country.
- E) The improvement of living standards
The degree of living improvement of people in a nation.

These evaluation functions are composed by 1) GNP 2) The amount of produced goods 3) Pollution degree of environment 4) Degree of distribution of produced goods, and so on.

23.4 Implementation

23.4.1 System Architecture

In order to run games of World Trade League, we are now implementing a server, client class structure, and sample clients programs. The architecture of the system is shown in Fig. 23.2. Although only one country exists in this figure, several countries are connected to the server in the real games or simulations.

The server consists of two modules, 1) Communication Control module, which controls all message transactions among agents, and 2) Database, which stores current status and all the history of each agent at micro-level and of the whole system at macro-level.

A module which collects requests from agents and acts as a mediator, such as market, is called 'medium' in order to distinguish it from regular agents existing in a nation.

All agents and mediums are prepared in class library, and users who wish to join the game can instantiate agent and medium instances from the library.

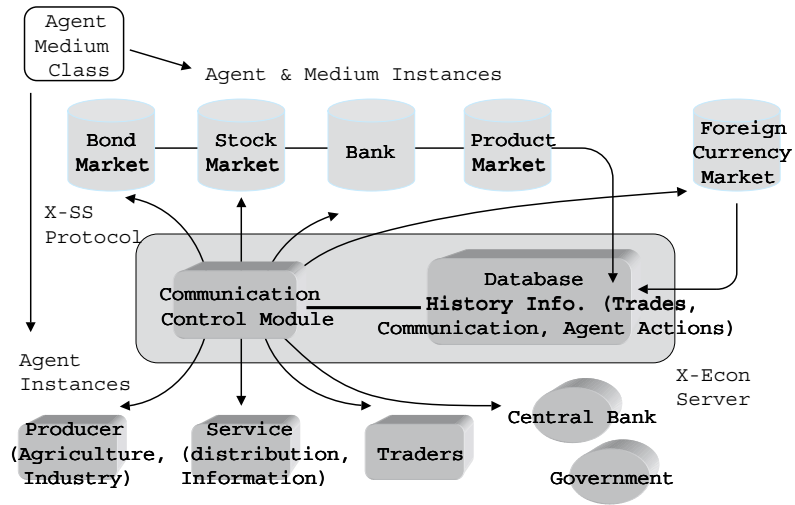


Fig. 23.2. System Architecture of World Trade League.

23.4.2 Communication Protocol *X-SS*

In World Trade League, a series of communication protocols called *X-SS* (eXtensible Social System) Protocol is prepared in order to reserve the extensibility of agent communications and game regulations [23.4].

Generally speaking, we have to prepare $n(n-1)/2$ types of protocol when n types of agents exist. In addition to it, we have to prepare n types of new protocols when adding a new type of agent. This way of protocol definition clearly have problems in computational complexity, extensionability, clarity, and easiness in understanding.

In *X-SS*, the protocol definition is not based on agent types, but on objects (goods, services, currency, or information) which are traded or exchanged in the game. For example, a trade of goods can be represented as an exchange of goods and currency, and collection and transmission of information as an exchange of information and currency. If you obtain free information, the price measured in currency should be set to zero. In addition to it, because one object to be traded or exchanged is almost always currency, we have to prepare just only m types of protocol where m is the number of objects to be exchanged in the system. Objects to be traded are as follows.

- Currency: Unique in the whole system, or prepared for each country. Local currency can be additionally defined.
- Goods: Food material, food, industrial material, industrial goods.

- Services: Transportation, amusement, general.
- Labor power
- Financial Goods: National bond, private bond, stock.
- Information

Using the protocol definition, an agent can be characterized by the goods which the agent can trade, and the class hierarchy of agents can be clearly defined.

We prepare several ways to define and implement the protocol and communication module, because agents and server can be implemented in several kinds of programming language and they may use several kinds of communication infrastructure:

- XML representation over networks in TCP/IP, UDP
- CORBA representation over networks in TCP/IP, UDP
- JAVA class library which represents message object
- C++ class library which represents message object

About the latter two types of message object, the communication between an agent and the server is carried out by 1) instantiating a message object instance from a message class, and by 2) calling proxy method implemented in the communication module of the server with setting the message object instance as an argument. The detail of protocol is, therefore, clearly defined as message class, and we can keep maintainability and extensibility of the protocol.

23.5 Requirements for Standard Problem in Multi-agent Economics

To propose standard problems in economic and social system research, we think that they have to satisfy the following requirements.

- Validity of the problem as a model of real systems:
Unlike the simulation in natural science, it is impossible to model and simulate the whole details of the target system in economic and social science. We have to extract the essence of the structure and behaviors of the target system, and to verify whether the simulation result can explain the essence of the target system. In other words, the setting of a standard problem should fit a suitable abstraction level of the target system.
- Applicability of several techniques to the problem:
A standard problem should be attacked by several types of techniques in social science, computer science, and artificial intelligence, e.g., dynamical system theory, game theory, agent-based simulation, machine learning techniques, and so on. In order to satisfy the criterion, the problem should be clearly described in computational sense and it should not include unnatural constraints.

- Complexity:
A problem should be complex enough, so that we cannot find the best strategy to easily solve the problem. Standard problems in artificial intelligence such as Chess, Shogi, and Igo have enough complexity in contrast with the simplicity and clearness of the game definition and settings.
- Closed problem rather than open problem:
A standard problem had better be a closed problem rather than open one. Because an open problem is influenced by information brought from outside of the target world, there is a possibility that the information gap among agents exists. In other words, the quantity and the quality of information for each player can vary, it is difficult to keep fairness among the players. Such shortcoming caused by openness becomes the essential difficulty when executing fair network games and strict simulations.

The game settings of World Trade League is designed to satisfy the above requirements.

23.6 Related Work

Multi-agent approach to market analysis called artificial market research is one of the active research areas, and many kinds of analysis have been carried out. Many fruitful simulation results have been already obtained in this area.

It seems difficult, however, to design network games in the context of market and trading. One of such network games is U-Mart, which is designed for a stock future market [23.5, 23.6]. This kind of approach has shortcomings that it is necessary to give information to agents from the outside of the system, e.g., so-called fundamental information (interest rate, benefit and business results of companies, perspective of national and international economics, etc.) must be unnaturally given to agents. This openness of the game crucially spoils the fairness among game participants.

Some research projects to model and analyze a whole economic system as multi-agent system have started. For instance, Virtual Economy Project [23.7, 23.8] provides a basic economic database for SNA based on Exchange Algebra. The approach lacks of the idea of agent design and of extending the framework to multi-nation environment.

Another approach to a whole economic system is Boxed-Economy Project [23.9, 23.10, 23.11]. They design the templates of economic agents as object class in detail, in order to construct a class structure of economic agents from the most genetic form to a specific one.

Our approach in World Trade League is to design both computational framework and agent class structure simultaneously. In that sense, our approach contains both directions of the above two approaches, and it provides a flexible common framework for network game, simulation, education, training, entertainment, and economic experiment.

World Trade League as a network game has a common characteristics with RoboCup Soccer [23.12], because both games consist of multi-players and each player itself is a multi-agent system, although World Trade League is a heterogeneous multi-agent system. World Trade League and RoboCup Rescue [23.13] uses multiple evaluation functions in order to evaluate complex aspects of target social systems.

23.7 Conclusion

We have proposed a framework called World Trade League which provides a standard problem in multi-agent economics. In the network game of World Trade League, several countries compete in order to achieve economic development of each own country with keeping cooperative relations with other countries and protecting environment.

A question is frequently asked: “Why do you call the game ‘World Trade League’ instead of ‘World Trade Game’ ?”

The answer is that we hope we find the path to achieve sustainable economic development in the game, with keeping the development of the whole world economic system, and with conserving the natural environment. The game should not become a field where a country which pursuits its own benefit obtain the best position.

We are now designing the detail of the network game in World Trade League, implementing common libraries *X-Economy* System based on *X-SS* protocols, and verifying the game as standard problem in detail. The regulations and game settings for public will be announced in the coming papers and on the web sites.

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24. Virtual Economy Simulation and Gaming —An Agent Based Approach—

Hiroshi Deguchi¹, Takao Terano², Koichi Kurumatani³, Taro Yuzawa⁴,
Shigeji Hashimoto⁵, Hiroyuki Matsui¹, Akio Sashima³, and
Toshiyuki Kaneda⁶

¹ Graduate School of Economics, Kyoto University

² Graduate School of Systems Management, University of Tsukuba

³ Cyber Assist Research Center, AIST.

⁴ Foundation for Fusion Of Science & Technology

⁵ KOEI NET Co.,Ltd.

⁶ Department of Systems Management and Engineering, Nagoya Institute of
Technology

In this paper we analyze an economic systems as agent based bottom up models. For the purpose we introduce a small national economy called a virtual economy and an exchange algebra for state space description. We construct dynamical agent based simulation model and analyze it.

24.1 Introduction

In this paper we construct a Simulation & Gaming model of a virtual economy. The virtual Economy consists of nine agents such as Agriculture, Milling Industry, Bread Industry (Bakery), Steel Industry, Machinery Industry, Government, Household, Bank and Central Bank. For the purpose an algebraic abstraction of bookkeeping system, which is called an exchange algebra, is introduced for describing micro economic exchange among agents. An economic state of each agent is also described by the algebra. Exchange algebra is an extension of accounting vector space [24.1, 24.2]. By using this algebras we describe systemic properties of economic exchange and properties of economic field. The economic field gives a formal model of SNA (System of National Account).

The virtual economy model is illustrated with Fig.24.1.

In the model economy agriculture grows wheat, milling industry makes wheat flour of wheat, bread industry (bakery) makes bread from flour, steel industry makes steel and machinery industry makes machinery from steel. In the model we assume that there are no materials for steel industry. Household purchases and consumes bread. Machines are purchased by industries as capital investments. The machines are used for production. Machines are also purchased by government or household. The machines that are purchased by government or household are considered as infrastructure and houses respectively. A machine depreciates according to a scenario. Population increases by a scenario. Household supplies workers to each industry and a government.

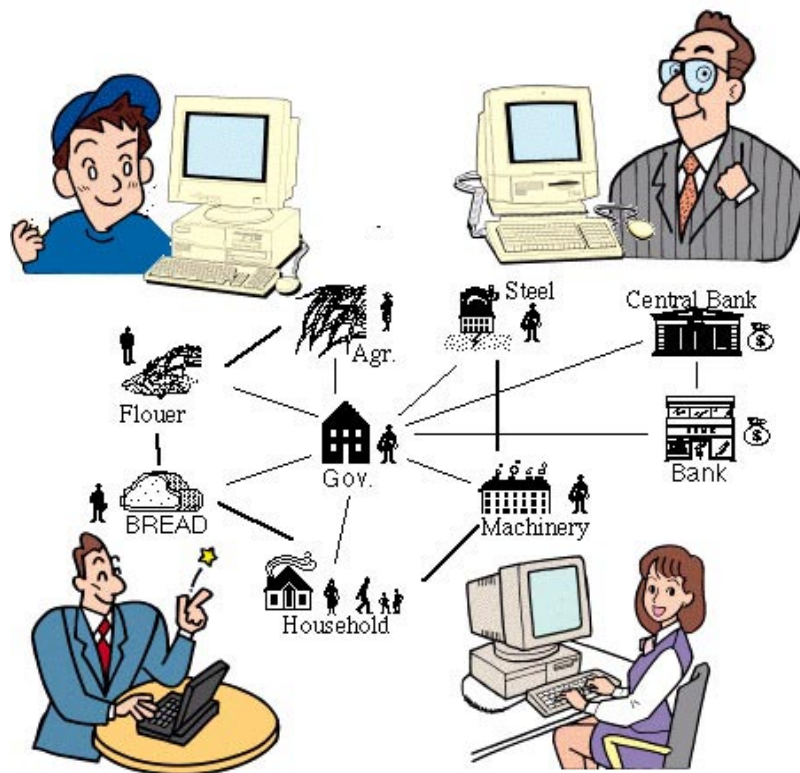


Fig. 24.1. Virtual Economy

Then household receives a wage. A government can issue national bonds. The central bank issues a bank note and fixes the official bank rate. Household and industries deposit money in a bank. A bank lends money.

24.2 Agent Based Simulation Model for Virtual Economy

In the virtual economy gaming players act as government, agriculture milling industry, bakery, steel industry, machinery industry, household, bank and central bank depending on their roles. This virtual economy becomes a multi agent model of an economic system of a country. In the economy players or machine agents act as decision makers. The game needs some basic assumptions. For example we have five products and one currency in this economy. We also assume proper units for the products and currency as follows. “MOU” stands for money unit such as dollar. “WHU” stands for wheat unit, “FLU”

stands for flour unit, “BRU” stands for bread unit, “STU” stands for steel unit and “MAU” stands for machine unit. They regard a machine as a house in the household.

We try to construct an agent based simulation model for this economy. Fig.24.2 shows the total design for the agent based simulation of the virtual economy.

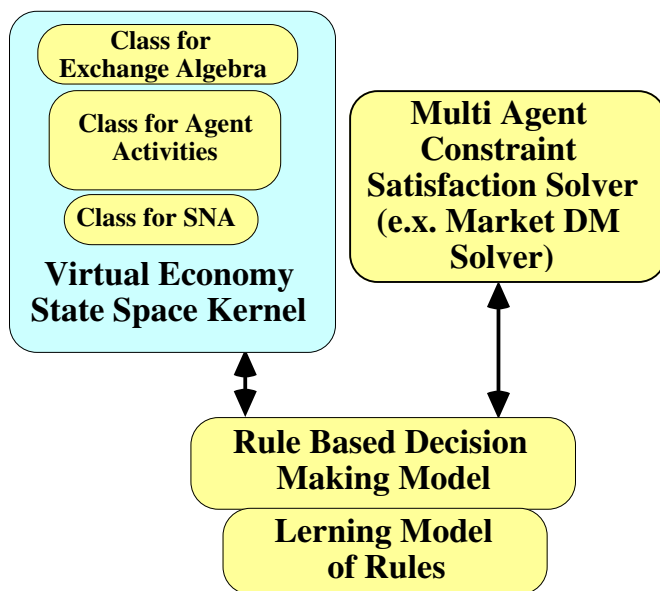


Fig. 24.2. Basic Design of the Agent Based Simulation Model of Virtual Economy

Fig.24.3 shows a prototype decision making model for a single human player. In this paper we introduce two types of dynamical models for this virtual economy gaming. The one is called the dictator’s view model. In this model a player has to make all decisions for transactions among agents of this economy in a term like a dictator. Table 24.1 shows decision making items for a player in a term.

The other is called the bird’s eye view model across the terms. In this model some decision is are made automatically depending on hidden decision making rules. A player makes a decision across the time in this model. In the former model decisions are made step by step in terms. But in the latter model a player has a bird’s eye view across the terms. In the model a player can observe total periods of economic development and makes a decision across the terms for achieving his aim in the economy.

Table 24.2 shows institutional parameters such as subsidy policy and national bond policy. A decision is made such as true or false. Table 24.3 shows

Table 24.1. Decision Making for Dictator’s View Model

	Agri	Flou	Bake.	Steel	Mach.	House	Gov.	CB	Bank
Income Tax Rate	*	*	*	*	*	*	0.1	*	*
Corporate Tax Rate	*	*	*	*	*	*	0.2	*	*
National Bond Rate	*	*	*	*	*	*	0.01	*	*
Official Bank Rate	*	*	*	*	*	*	*	0.01	*
Deposits in CB	*	*	*	*	*	*	*	0	0
Withdraw from CB	*	*	*	*	*	*	*	0	0
Loan from CB	*	*	*	*	*	*	*	1000	1000
Refund to CB	*	*	*	*	*	*	*	0	0
Receive Subsidy	0	0	10	10	10	0	30	*	0
Deposit Interest	*	*	*	*	*	*	*	*	0.01
Loan Interest	*	*	*	*	*	*	*	*	0.03
Buy National Bond(NB)	0	0	0	0	0	0	0	*	*
Redeem NB	0	0	0	0	0	0	0	*	*
Accept NB by CB	*	*	*	*	*	*	0	0	*
Redeem NB from CB	*	*	*	*	*	*	0	0	*
Loan from Bank	0	300	100	300	300	0	*	*	1000
Redeem to Bank	0	0	0	0	0	0	*	*	0
Deposit in Bank	0	0	0	0	0	0	*	*	0
Withdraw from Bank	0	0	0	0	0	0	*	*	0
Product Price per Unit	0.2	0.5	1	6.25	11	*	*	*	*
Capital Investment (numbers)	2	3	2	4	8	2	0	*	*
Sales of Products (Quantity)	770	580	420	14	21	*	*	*	*
Numbers of Employment	70	70	60	30	65	330	35	*	*
Total Wage	90	90	80	30	90	430	50	*	*

Table 24.2. Institutional Parameters

Adoption of a Policy : Institutional Parameters										
	1	2	3	4	5	6	7	8	9	10
Subsidy for Half the Capital Investment	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	FALSE	FALSE	FALSE	FALSE
Subsidy for the Deficit of Makers	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Subsidy for Half the House Investment	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Issue National Bond under guarantee of Central Bank	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE

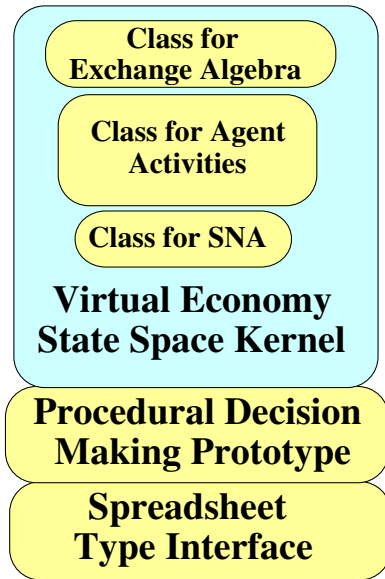


Fig. 24.3. Prototype Decision Making Model for a Single Human Player

Table 24.3. Capital Investment

Term	Machine available	Agri .	Flour	Bakely	Stee 1	Machine	House hold	Gov.	Sum	Stock of Machine
1	26	2	4	1	7	11	1	0	26	0
2	35	2	5	4	10	14	0	0	35	0
3	44	2	5	6	10	19	2	0	44	0
4	55	2	10	8	10	23	1	0	54	1
5	62	3	15	10	10	22	2	0	62	0
6	75	2	15	17	12	25	3	1	75	0
7	81	4	17	15	10	28	4	3	81	0
8	81	5	21	13	16	24	2	0	81	0
9	88	5	22	13	10	33	3	2	88	0
10	97	3	30	15	13	32	3	0	96	1

Table 24.4. Management and Political Decisions

Management & Political Decisions of Agents										
Term	1	2	3	4	5	6	7	8	9	10
Income Tax Rate	0.1	0.05	0.05	0.05	0.02	0.02	0.05	0.05	0.05	0.05
Corporate Tax Rate	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
National Bond Rate	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Official Bank Rate	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Deposit Interest	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Loan Interest	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Price Wheat	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Price Flour	0.5	0.5	0.5	0.52	0.52	0.52	0.52	0.52	0.52	0.52
Price Bread	1	1	1	1	1	1	1.1	1.1	1.1	1.1
Price Steel	6.25	6.25	6.25	6.5	6.5	6.5	6.5	6.5	6.5	6.5
Price Machine	10	10	10	10	10	10	10	10	10	10
Wage(Agr.)/Person	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Wage(Flou.)/Person	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Wage(Bake.)/Person	1.3	1.3	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Wage(Steel)/Person	1	1.1	1.2	1.3	1.5	1.5	1.5	1.5	1.5	1.5
Wage(Mach.)/Person	1.3	1.3	1.4	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Wage(Gov.)/Person	1.4	1.4	1.4	1.4	1.5	1.5	1.5	1.5	1.5	1.5

capital investment of each agent in each term. Table 24.4 shows management and political parameters.

A player can observe several types of economic developments across the terms while he change these parameters. A player can set up different goals depending on the social indexes on which he is focussing such as the numbers of residents per house, GDP per person and foods consumption per person.

24.3 Result of Simulation

We show the results of economic developments in ten terms. The following figures show the results of simulation by bird's eye view model across the terms under the parameters of the previous tables. Fig.24.4 shows the numbers of residents per house. Fig.24.5 shows GDP per person and food consumption per person. Fig.24.6 shows price index. Fig.24.7 shows cash in the government and issued national bonds which are accepted in the central bank.

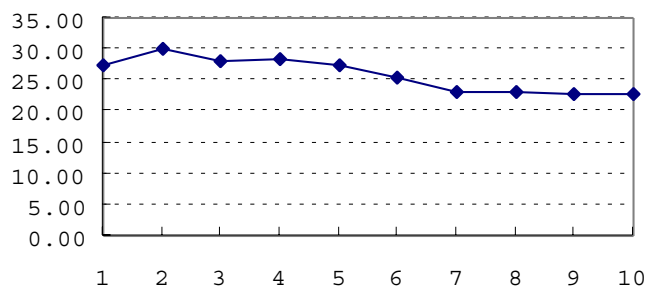


Fig. 24.4. The Numbers of Residents per House



Fig. 24.5. GDP (Real) per Person & Food Consumption (BRU) per Person

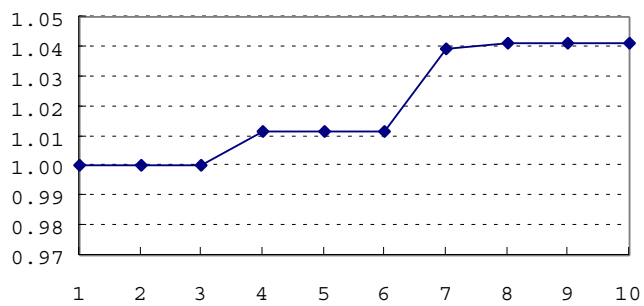


Fig. 24.6. Price Index

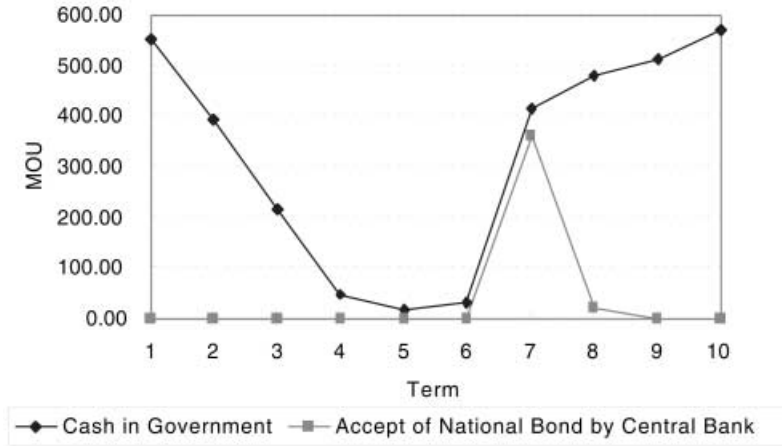


Fig. 24.7. Cash in Government and Issued National Bond Accepted in Central Bank

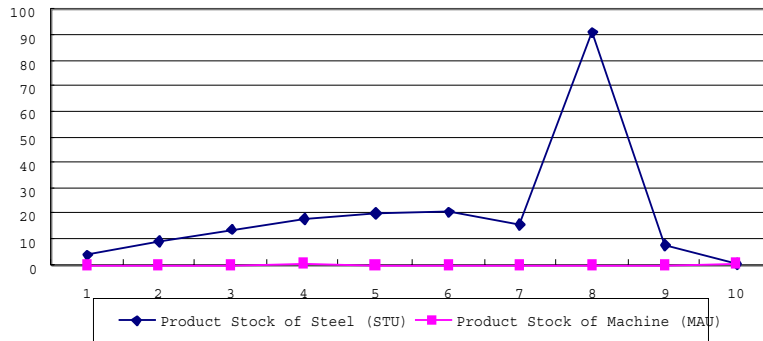


Fig. 24.8. Product Stock of Steel and Machine

24.4 Conclusion

We investigated an agent based simulation model of a small national economy. The model is different from usual macro economic model. We assumed bottom up state description of an economic agent by exchange algebra. We can add multi agent decision making mechanism in the model from bottom up point of view as is shown in Fig.24.2. We want to express and design the institutional and structural varieties of real economy in agent based models. This is a first step for our research program.

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25. Boxed Economy Foundation Model: Model Framework for Agent-Based Economic Simulations

Takashi Iba^{1,2,3}, Yohei Takabe⁴, Yoshihide Chubachi⁴,
Junichiro Tanaka¹, Kenichi Kamihashi¹, Ryunosuke Tsuya¹,
Satomi Kitano¹, Masaharu Hirokane¹, and Yoshiaki Matsuzawa¹

¹ Keio University, 5322 Endo, Fujisawa, Kanagawa, Japan

² JSPS Research Fellow

³ Research Associate of Fujita Institute of Future Management Research,
Hibiya bldg. 1-1, 1-chome, Shinbashi, Minato, Tokyo, Japan

⁴ Keio Research Institute at SFC, 5322 Endo, Fujisawa, Kanagawa, Japan

25.1 Introduction

The recent advancement of the agent-based modeling and simulation has been revolutionizing the social sciences and other research fields. The agent-based approach enables us to deal with the model that generates macroscopic phenomena by allowing numbers of agents to act at the micro level within the simulation. Therefore, in the social sciences, we can trace and understand the internal mechanisms in society. Since some interesting implications have been derived from the former researches with agent-based approach, expectations are rising in social sciences.

In the last some years, several tools for agent-based simulations have been proposed: Swarm Simulation System[25.10], Ascape[25.11], RePast[25.12], MAML[25.7] and so on. Especially Swarm Simulation System has become one of the most famous and most growth toolkit in many research fields. Although these tools have promoted to share some kind of components such as Graphical User Interfaces (GUI) among researchers, they have been less successful in sharing and cumulating the parts of simulation models. It is because the provided basis are too high abstract for users to follow when they build the sharable components. To design the sharable and reusable models, the domain-specific design is required at the level of social model rather than the level of abstract general-purpose model. To put it another way, the social scientists really need not only the abstract basis, such as mathematical operators, but also the model components, such as production function or consumption function in economics. Indeed, economists usually specify their model with using the typical model components. There are, for example, some types of production functions: Cobb-Douglas type, CES type,

and Translog type in economics. They hardly ever make the model components from scratch each time¹.

We, then, would like to provide the model framework specializing in agent-based model of economic society, incorporating the idea of object-oriented framework that define the basic architecture of economic and social models[25.8]². We call our model framework “Boxed Economy Foundation Model”.

25.2 Model Framework for Agent-Based Economic Simulations

Boxed Economy Foundation Model provides the framework for modeling the economic society. The foundation model is an abstract model of a real society from the viewpoint of economy. We would like to suggest especially that the design with object-oriented framework is more significant than the design simply with components or objects in the field of the economic and social simulations. This is because the introduction of the frameworks makes it easier for the simulation builders to build, share and co-improve the economic simulations.

Framework is the architecture that is specialized to a certain domain. Framework provides many kinds of plug-points (container) to connect the components that would be implemented by the simulation builders in each simulation(Fig. 25.1). Frameworks is important for reusing and co-improving due to define a “context” for the components developed in the future, although it is usually difficult to combine the components developed by independent groups, because they have inconsistent assumptions each other.

To build a realistic model step by step, it is necessary to urge the researchers and some businessperson from other areas to participate in the development. Boxed Economy introduces the idea of framework to simulate the economic society and keep the architecture on one track. Therefore, the simulation builders can make the models in parallel as long as they keep the same framework, and they can concentrate on the object related to their major: consumer, corporation, and so on.

25.3 Boxed Economy Foundation Model

Boxed Economy Foundation Model has the definition of the fundamental relationship between each part of artificial economy model. Fig. 25.2 shows

¹ Most of the simulation models are built from scratch each time in agent-based research. Enormous developing time and costs are required in this style.

² C.Bruun[25.4] has similar motivation and also try to make model framework for agent-based economic simulations. There is, however, critical differences in regard to the agent design, as we will mention later.

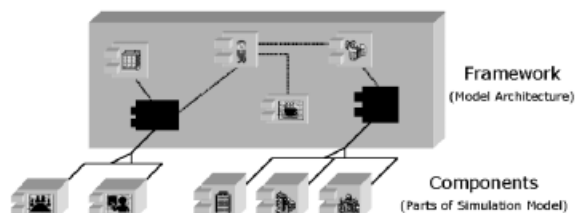


Fig. 25.1. Object-Oriented Framework and Components

the classes and their relationships in the Boxed Economy Foundation Model which is expressed in Unified Modeling Language (UML)[25.2]. The main part of the foundation model currently contains 14 classes and they are called “foundation model class”. The classification is as follows³:

- EconomicActor, SocialGroup, Individual
- Goods, Information, Possession
- Behavior, BehaviorManagement, Memory, Needs
- Relation, Path
- Clock, Location

An “agent” can be a representative of any autonomous subjects in the economy. It means that each individuals and social groups such as government or corporations are all dealt as “agent” in the model. The “agent” which is defined in the Boxed Economy, is formed by the following classes: [EconomicActor] as its core, [Behavior], [BehaviorManagement] and [Memory]. [EconomicActor] reacts with these classes that surround it and becomes an agent in artificial economy.

In the rest of this section, we would like to introduce the definition of some classes, their correspondence to the real society and the relationship with other classes in the model by catalog style.

25.3.1 EconomicActor, SocialGroup, Individual

[EconomicActor]

Definition: An actor who carries economic activities in the artificial society.

Correspondence: Human or social group as consumer, corporation, bank, government, etc.

³ The design and definitions of Boxed Economy Foundation Model are a temporary statement and they might be changed in the future.

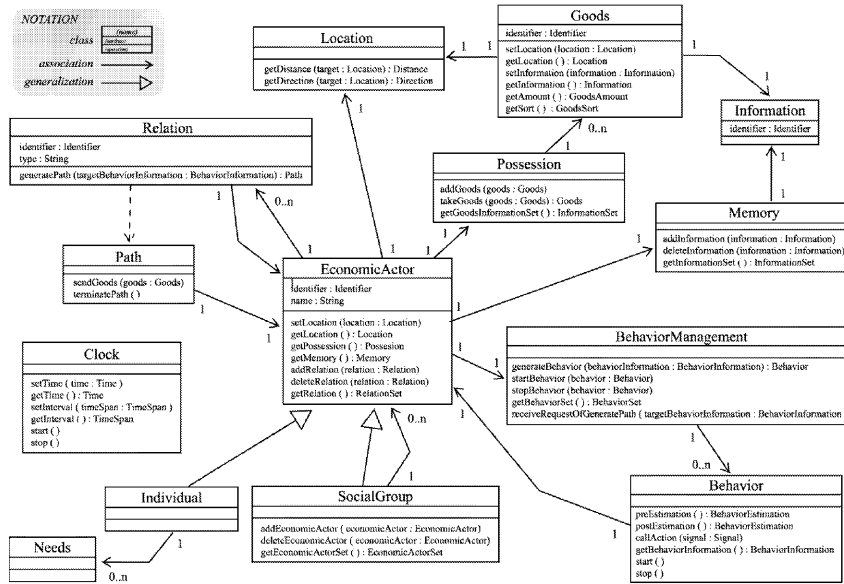


Fig. 25.2. Main Architecture of Boxed Economy Foundation Model

Explanation: [EconomicActor] is the core element that executes the economic activities. [Behavior], [BehaviorManagement] and [Memory] are added in order to create an “agent”. [EconomicActor] stands for the [Individual] and the [SocialGroup].

Related Class: [EconomicActor] owns one [Memory], [BehaviorManagement] and more than one [Behavior]. Also it owns many [Goods] and exchange them through [Path] which will be created based on the [Relation] they have.

[SocialGroup]

Definition: A group which is formed by the [EconomicActor].

Correspondence: Social group as corporation, regional community, etc.

Explanation: [SocialGroup] is one kind of [EconomicActor]. [SocialGroup] consists of [EconomicActor] or other [SocialGroup]. Note that it is possible to have [SocialGroup] inside another group.

Related Class: This class is extended from the [EconomicActor] class and inherits all the characteristics, it holds [Memory], [Behavior], [BehaviorManagement], [Goods], [Relation] and [Path].

[Individual]

- Definition:* A single human being in the artificial society.
- Correspondence:* Human being.
- Explanation:* [Individual] is one kind of [EconomicActor]. The differences between [Individual] and [SocialGroup] is that [Individual] may have the [Needs]. [Individual] is the minimum unit to form [SocialGroup].
- Related Class:* This class is extended from the [EconomicActor] class and inherit its characteristics, then contains [Memory], [Behavior], [BehaviorManagement], [Goods], [Relation], and [Path].

25.3.2 Goods, Information, Possession**[Goods]**

- Definition:* Everything that is owned or exchanged by [EconomicActor]. Also can be something that is invisible.
- Correspondence:* Commodities, service, money, etc.
- Explanation:* [Goods] has the following attributes, name, kind, visibility, date of produce, basic endurance, portability, divisibility, amount, unit of measurement, etc. Career of information and also money as well are treated as a kind of [Goods].
- Related Class:* [Goods] is named as [Possession] when it is owned by [EconomicActor]. [Information] is always exchanged with some kind of [Goods] as a carrier not by itself.

[Information]

- Definition:* Knowledge which is an expression of many facts.
- Correspondence:* Knowledge stored in documents, the contents of communications and advertisement, etc.
- Explanation:* [Information] does not stand by itself, but is always a thing which is contained by [Goods]. For example when papers contain the [Information], it will be a document, and when voice becomes the carrier it will be a verbal communication. When information reaches the [EconomicActor], it will be decoded into [Memory].
- Related Class:* [Information] is always exchanged with some kind of [Goods] as a carrier not by itself.

25.3.3 Behavior, BehaviorManagement, Memory, Needs

[Behavior]

Definition: An element to construct the decision and action of the economic actor.

Correspondence: The corporate behaviors of strategic decision-making, production, sales, etc. And the individual behavior of purchase decision-making, information processing, etc.

Explanation: Each of decision-making and behavior is defined as the behavior. Each [EconomicActor] is able to execute the decision-making and behavior which is defined by [Behavior] it has.

Related Class: It is held in [EconomicActor].

[Memory]

Definition: Knowledge that is stored in the economic actor.

Correspondence: Things that somebody knows, etc.

Explanation: [Memory] would be referred to when the agent has to make a decision. By time to time, memory would be refreshed by its experience.

Related Class: It is stored in [EconomicActor].

[Needs]

Definition: A drive that motivates individual to an action.

Correspondence: Desire of human.

Explanation: [Needs] is a thing that [Individual] holds as a mechanism of action, but a [SocialGroup] does not have this. The state of lack drives the [individual] to some kind of action and the desire would be fulfilled.

Related Class: It is held by [individual].

25.3.4 Relation, Path

[Relation]

Definition: A state that [EconomicActor] knows some other [EconomicActor].

Correspondence: The relationship of family, friends, labor, neighborhood, etc.

Explanation: Having [Relation] is a state that the communication is enabled. By the [Information] which the agent gains, there would be a new [Relation] constructed. [Relation] would be normally expressed as a one-way but when both of them connects each other it will be two-way.

Related Class: It is held by an [EconomicActor].

[Path]

- Definition:* A path created with its relation to communicate with other economic actor.
- Correspondence:* A path to exchange items or to communicate with others.
- Explanation:* Items or contents of verbal communication we would be exchanged through out this path. For example, retailer will open a path to the customer to give the item to him/her.
- Related Class:* [EconomicActor] will create a path by its [Relation] and the [Path] enables to pass the [Goods] to one another.

25.4 Applying Boxed Economy Foundation Model**25.4.1 Modeling Behavior Rather than Agent**

When you want to create a simulation based on Boxed Economy, you will be describing the details of the agents by using the class definition, which you have just read through.

We would like to emphasize that it is important to characterize the agent as an object that has more than one behavior. This representation of the agent is epoch-making and has more advantage than the conventional models which also handle the agent as a minimum indivisible unit in a simulation[25.3][25.1][25.6]. The advantage is that in this way it will be possible to describe an agent to act more than one social role. For example, most of the individuals would act as “consumers” if they buy some items from the store, and would act as “labors” if they work to earn money. The point is that we do not have the subject called consumers or labors, but the subject we have in our society is only individual persons which act the role of consumer or labor in each scenes. In the Boxed Economy, we follow this idea and create the agent as an individual person that has the behavior of consumer, and we do not create a consumer agent. As a summary, to create the model of economic actor by using the Boxed Economy Foundation Model would be the modeling the behaviors that the economic actor has.

25.4.2 Flexibility on the Boundary of Agent

Boxed Economy provides the ability to the agents to be dynamic inside it. In other words, the agent based on the foundation model will be able to decide its own boundary. There are three ways of changing boundary.

The first way of changing the boundary is to increase/decrease the number of actors inside it. Corporation agent, for example, will be able to change the number of workers by hiring and firing.

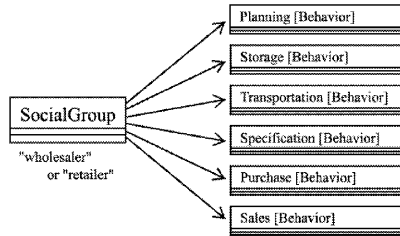


Fig. 25.3. Representation of Wholesaler or Retailer

The second way of changing the boundary would be done by exchanging, increasing or decreasing the behavior that the agent has. Since the agent in the model is defined as an object that has the behaviors to make decisions or doing some kinds of actions, the functional boundary of the agent can be changed by adding/deleting its behaviors. For instance, if you want to let the seller agent to obtain the part of banking functions, it will be realized by adding the behavior of banking function to the seller agent.

The third way of changing the boundary is to generate a new agent (can be individual or social group) or to disappear the existing agent. It may be birth or death for individuals, marriage or divorce will apply to families, foundation or bankruptcy for corporations.

By providing the agents with the ability mentioned above, the agents in the simulation will be able to change and adjust themselves to the situation as time goes by. Since the analysis with artificial economy is often focused to observe the long-term movements in the whole economy, we need to implement this behavior to the agent.

25.4.3 Example: Sellers in Distribution Mechanism

The mechanism of distribution include corporations which stand for producer, wholesaler and retailer in its structure. Both wholesaler and retailer mostly has the same behavior, but retailer only sells its items to the consumer and wholesaler is a reseller of products to anyone except the consumers. In the Boxed Economy we do not model the agents as wholesalers or retailers, instead we define the agents by dividing their decision-making and action by its behaviors (Fig. 25.3). In this way, it will be possible for many subjects to have the same behavior, and will provide expandability to the agents.

In the fundamental model, we can create the social group within the social group: for instance, if you imagine departments in a corporation, both departments and corporation would be a [SocialGroup] (Fig. 25.4). And by using this idea we will be able to out-source some of the functions to others or we can also create a transportation business that only has the function of transportation. In the real world, there are movements of out-sourcing the

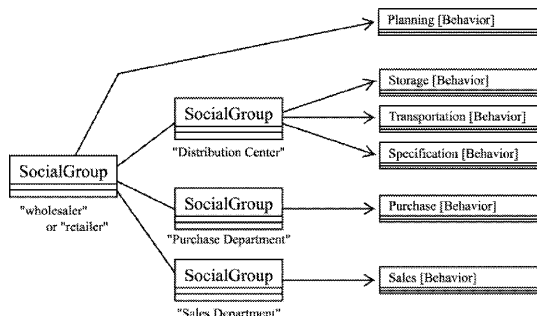


Fig. 25.4. Representation of Wholesaler or Retailer (in the Case of Department Structure)

function, or merge the whole structure of the corporation, and we will be ready to simulate such situations by modeling them with its behavior⁴.

25.5 Conclusion

In this paper, we proposed the concept and design of “Boxed Economy Foundation Model”, which is a sharable model framework for agent-based economic simulations. Here we should note that we have developed “Boxed Economy Simulation Platform”, which realizes the simulation environment for the simulation model based on Boxed Economy Foundation Model[25.9]. The platform is implemented by Java, which is portable and independent of the computer platform, and will be opened to public before soon (Fig. 25.5).

Creating the foundation for the social simulation researches is an oversized project for our members to complete. We would like to realize this by collaborating with many researchers in various fields. Please contact us on <http://www.boxed-economy.org/>, if you are interested in our challenge.

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⁴ The design that separates behaviors from the class is of great advantage not only to build flexible social models but also to build flexible software. To delegate the role to other objects, which is called “composition”, is more flexible than inheritance, and is known as close way to the essence of object-oriented design[25.5].

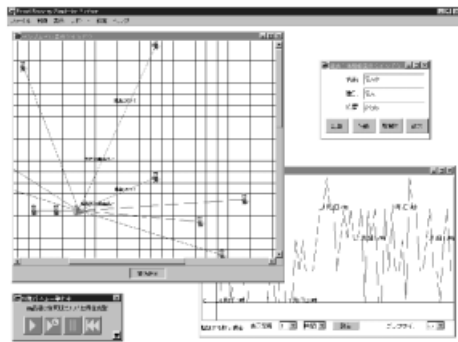


Fig. 25.5. Boxed Economy Simulation Platform

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26. Workshop on Rough Set Theory and Granular Computing – Summary

Shusaku Tsumoto¹, Shoji Hirano¹, and Masahiro Inuiguchi²

¹ Shimane Medical University, Izumo, 693-8501 Japan
{tsumoto,hirano}@shimane-med.ac.jp

² Graduate School of Engineering, Osaka University,
Suita, Osaka 565-0871, Japan
inuiguti@eie.eng.osaka-u.ac.jp

Rough sets was proposed by Z. Pawlak in 1980 as the way how real-world concepts can be approximated by human measurements. For example, in a database, real-world concepts were approximated by the combination of attributes, as lower and upper approximation. The formal studies on this approximation can be viewed as the computation of information granularity, which are closely related with data mining, machine learning, multi-valued logic and fuzzy sets.

The workshop on rough sets and granular computing started from May 20 due to the number of paper submissions (30). The workshop consisted of three invited talks by Z. Pawlak, A. Skowron and S.K.Pal and 30 presentations of regular papers (3: inductive logic programming (ILP), 3: decision making, 5: rule induction, 3: fuzzy logic, 3: granular computing, 5: fundamentals of rough sets, 6: applications, 2: conflict analysis). The number of attendees in this workshop was 42 in total (22: Japan, 5: Poland, 3: India, 2: US, 1: Korea, 6: PhD students of Shimane University and Shimane Medical University).

In the invited talks, Pawlak discussed the relations between rough sets and Bayesian inference and the Lukasiewicz multi-valued logic as a key notion of the bridge between rough sets and Bayesian reasoning. In the second talk, Skowron reviewed the studies on rough sets which plays important roles in the estimation of information granularity and discussed the potentials of granular computing in multi-agent systems. In the final talk, Pal discussed the importance of rough sets, fuzzy sets and genetic algorithms in data mining.

In the regular sessions, not only the applications of rough sets but also several fundamental studies on the extensions of rough sets were presented. Also, theoretical studies on the combinations of rough sets and other methods, such as inductive logic programming and fuzzy reasoning were shown. These invited talks and regular papers showed that rough sets are widely used as an important tool for data mining and data analysis and that rough sets should be recognised as a fundamental tool for the theoretical studies on approximate reasoning.

27. Bayes' Theorem Revised – The Rough Set View

Zdzisław Pawlak

Institute of Theoretical and Applied Informatics, Polish Academy of Sciences,
ul. Bałtycka 5, 44 100 Gliwice, Poland

Rough set theory offers new insight into Bayes' theorem. The look on Bayes' theorem offered by rough set theory is completely different from that used in the Bayesian data analysis philosophy. It does not refer either to prior or posterior probabilities, inherently associated with Bayesian reasoning, but it reveals some probabilistic structure of the data being analyzed. It states that any data set (decision table) satisfies total probability theorem and Bayes' theorem. This property can be used directly to draw conclusions from data without referring to prior knowledge and its revision if new evidence is available. Thus in the presented approach the only source of knowledge is the data and there is no need to assume that there is any prior knowledge besides the data. We simply look what the data are telling us. Consequently we do not refer to any prior knowledge which is updated after receiving some data.

27.1 Introduction

This paper is an abbreviation of [27.8]

Bayes' theorem is the essence of statistical inference.

"The result of the Bayesian data analysis process is the posterior distribution that represents a revision of the prior distribution on the light of the evidence provided by the data" [27.5].

"Opinion as to the values of Bayes' theorem as a basic for statistical inference has swung between acceptance and rejection since its publication on 1763" [27.4].

Rough set theory offers new insight into Bayes' theorem. The look on Bayes' theorem offered by rough set theory is completely different to that used in the Bayesian data analysis philosophy. It does not refer either to prior or posterior probabilities, inherently associated with Bayesian reasoning, but it reveals some probabilistic structure of the data being analyzed. It states that any data set (decision table) satisfies total probability theorem and Bayes' theorem. This property can be used directly to draw conclusions from data without referring to prior knowledge and its revision if new evidence is available. Thus in the presented approach the only source of knowledge is the data and there is no need to assume that there is any prior knowledge besides the data. We simply look what the data are telling us. Consequently

we do not refer to any prior knowledge which is updated after receiving some data.

Moreover, the rough set approach to Bayes' theorem shows close relationship between logic of implications and probability, which was first observed by Łukasiewicz [27.6] and also independently studied by Adams [27.1] and others. Bayes' theorem in this context can be used to "invert" implications, i.e. to give reasons for decisions. This is a very important feature of utmost importance to data mining and decision analysis, for it extends the class of problem which can be considered in these domains.

Besides, we propose a new form of Bayes' theorem where basic role plays strength of decision rules (implications) derived from the data. The strength of decision rules is computed from the data or it can be also an subjective assessment. This formulation gives new look on Bayesian method of inference and also essentially simplifies computations.

27.2 Bayes' Theorem

In this section we recall basic ideas of Bayesian inference philosophy, after recent books on Bayes' theory citeber:smi,box:tia,bert:han.

In his paper [27.2] Bayes considered the following problem: "Given the number of times in which an unknown event has happened and failed: *required* the chance that the probability of its happening in a single trial lies somewhere between any two degrees of probability that can be named."

"The technical results at the heart of the essay is what we now know as *Bayes' theorem*. However, from a purely formal perspective there is no obvious reason why this essentially trivial probability result should continue to excite interest" [27.3].

"In its simplest form, if H denotes an hypothesis and D denotes data, the theorem says that

$$P(H|D) = P(D|H) \times P(H) / P(D).$$

With $P(H)$ regarded as a probabilistic statement of belief about H before obtaining data D , the left-hand side $P(H|D)$ becomes an probabilistic statement of belief about H after obtaining D . Having specified $P(D|H)$ and $P(D)$, the mechanism of the theorem provides a solution to the problem of how to learn from data.

In this expression, $P(H)$, which tells us what is known about H without knowing of the data, is called the *prior* distribution of H , or the distribution of H *a priori*. Correspondingly, $P(H|D)$, which tells us what is known about H given knowledge of the data, is called the *posterior* distribution of H given D , or the distribution of H *a posteriori*" [27.3].

"A prior distribution, which is supposed to represent what is known about unknown parameters before the data is available, plays an important role in

Baysian analysis. Such a distribution can be used to represent prior knowledge or relative ignorance" [27.4].

Let us illustrate the above by a simple example taken from [27.5].

Example 27.2.1. "Consider a physician's diagnostic test for presence or absence of some rare disease D , that only occurs in 0.1% of the population, i.e., $P(D) = .001$. It follows that $P(\bar{D}) = .999$, where \bar{D} indicates that a person does not have the disease. The probability of an event before the evaluation of evidence through Bayes' rule is often called the prior probability. The prior probability that someone picked at random from the population has the disease is therefore $P(D) = .001$.

Furthermore we denote a positive test result by T^+ , and a negative test result by T^- . The performance of the test is summarized in Table 1.

Table 27.1. Performance of diagnostic test

	T^+	T^-
D	0.95	0.05
\bar{D}	0.02	0.98

What is the probability that a patient has the disease, if the test result is positive? First, notice that D, \bar{D} is a partition of the outcome space. We apply Bayes' rule to obtain

$$\begin{aligned}
 P(D|T^+) &= \frac{P(T^+|D)P(D)}{P(T^+|D)P(D) + P(T^+|\bar{D})P(\bar{D})} = \\
 &= \frac{.95 \cdot .001}{.95 \cdot .001 + .02 \cdot .999} = .045.
 \end{aligned}$$

Only 4.5% of the people with a positive test result actually have the disease. On the other hand, the posterior probability (i.e. the probability after evaluation of evidence) is 45 times as high as the prior probability". \square

27.3 Information Systems and Approximation of Sets

In this section we define basic concepts of rough set theory: information system and approximation of sets. Rudiments of rough set theory can be found in [27.7, 27.10].

An information system is a data table, whose columns are labeled by attributes, rows are labeled by objects of interest and entries of the table are attribute values.

Formally, by an *information system* we will understand a pair $S = (U, A)$, where U and A , are finite, nonempty sets called the *universe*, and the set of *attributes*, respectively. With every attribute $a \in A$ we associate a set V_a , of its *values*, called the *domain* of a . Any subset B of A determines a binary relation $I(B)$ on U , which will be called an *indiscernibility relation*, and defined as follows: $(x, y) \in I(B)$ if and only if $a(x) = a(y)$ for every $a \in B$, where $a(x)$ denotes the value of attribute a for element x . Obviously $I(B)$ is an equivalence relation. The family of all equivalence classes of $I(B)$, i.e., a partition determined by B , will be denoted by $U/I(B)$, or simply by U/B ; an equivalence class of $I(B)$, i.e., block of the partition U/B , containing x will be denoted by $B(x)$.

If (x, y) belongs to $I(B)$ we will say that x and y are *B-indiscernible* (*indiscernible with respect to B*). Equivalence classes of the relation $I(B)$ (or blocks of the partition U/B) are referred to as *B-elementary sets* or *B-granules*.

If we distinguish in an information system two disjoint classes of attributes, called *condition* and *decision attributes*, respectively, then the system will be called a *decision table* and will be denoted by $S = (U, C, D)$, where C and D are disjoint sets of condition and decision attributes, respectively.

Thus the decision table determines decisions which must be taken, when some conditions are satisfied. In other words each row of the decision table specifies a decision rule which determines decisions in terms of conditions.

Observe, that elements of the universe are in the case of decision tables simply labels of decision rules.

Suppose we are given an information system $S = (U, A)$, $X \subseteq U$, and $B \subseteq A$. Our task is to describe the set X in terms of attribute values from B . To this end we define two operations assigning to every $X \subseteq U$ two sets $B_*(X)$ and $B^*(X)$ called the *B-lower* and the *B-upper approximation* of X , respectively, and defined as follows:

$$B_*(X) = \bigcup_{x \in U} \{B(x) : B(x) \subseteq X\},$$

$$B^*(X) = \bigcup_{x \in U} \{B(x) : B(x) \cap X \neq \emptyset\}.$$

Hence, the *B-lower approximation* of a set is the union of all *B-granules* that are included in the set, whereas the *B-upper approximation* of a set is the union of all *B-granules* that have a nonempty intersection with the set. The set

$$BN_B(X) = B^*(X) - B_*(X)$$

will be referred to as the *B-boundary region* of X .

If the boundary region of X is the empty set, i.e., $BN_B(X) = \emptyset$, then X is *crisp (exact)* with respect to B ; in the opposite case, i.e., if $BN_B(X) \neq \emptyset$, X is referred to as *rough (inexact)* with respect to B .

27.4 Rough Membership

Rough sets can be also defined employing instead of approximations rough membership function [27.9], which is defined as follows:

$$\mu_X^B : U \rightarrow [0, 1]$$

and

$$\mu_X^B(x) = \frac{|B(x) \cap X|}{|B(x)|},$$

where $X \subseteq U$ and $B \subseteq A$.

The function measures the degree that x belongs to X in view of information about x expressed by the set of attributes B .

The rough membership function, can be used to define approximations and the boundary region of a set, as shown below:

$$B_*(X) = \{x \in U : \mu_X^B(x) = 1\},$$

$$B^*(X) = \{x \in U : \mu_X^B(x) > 0\},$$

$$BN_B(X) = \{x \in U : 0 < \mu_X^B(x) < 1\}.$$

27.5 Information Systems and Decision Rules

Every decision table describes decisions (actions, results etc.) determined, when some conditions are satisfied. In other words each row of the decision table specifies a decision rule which determines decisions in terms of conditions.

In what follows we will describe decision rules more exactly.

Let $S = (U, C, D)$ be a decision table. Every $x \in U$ determines a sequence $c_1(x), \dots, c_n(x), d_1(x), \dots, d_m(x)$ where $\{c_1, \dots, c_n\} = C$ and $\{d_1, \dots, d_m\} = D$.

The sequence will be called a *decision rule (induced by x)* in S and denoted by $c_1(x), \dots, c_n(x) \rightarrow d_1(x), \dots, d_m(x)$ or in short $C \rightarrow_x D$.

Decision rules are often presented as logical implications in the form "if...then...".

A set of decision rules corresponding to a decision table will be called a *decision algorithm*.

The number $supp_x(C, D) = |C(x) \cap D(x)|$ will be called a *support* of the decision rule $C \rightarrow_x D$ and the number

$$\sigma_x(C, D) = \frac{supp_x(C, D)}{|U|},$$

will be referred to as the *strength* of the decision rule $C \rightarrow_x D$, where $|X|$ denotes the cardinality of X . With every decision rule $C \rightarrow_x D$ we associate

the *certainty factor* of the decision rule, denoted $cer_x(C, D)$ and defined as follows:

$$\begin{aligned} cer_x(C, D) &= \frac{|C(x) \cap D(x)|}{|C(x)|} = \frac{supp_x(C, D)}{|C(x)|} = \\ &= \frac{\sigma_x(C, D)}{\pi(C(x))}, \end{aligned}$$

where $\pi(C(x)) = \frac{|C(x)|}{|U|}$.

The certainty factor may be interpreted as a conditional probability that y belongs to $D(x)$ given y belongs to $C(x)$, symbolically $\pi_x(D|C)$.

If $cer_x(C, D) = 1$, then $C \rightarrow_x D$ will be called a *certain decision rule* in S ; if $0 < cer_x(C, D) < 1$ the decision rule will be referred to as an *uncertain decision rule* in S .

Besides, we will also use a *coverage factor* of the decision rule, denoted $cov_x(C, D)$ defined as

$$\begin{aligned} cov_x(C, D) &= \frac{|C(x) \cap D(x)|}{|D(x)|} = \frac{supp_x(C, D)}{|D(x)|} = \\ &= \frac{\sigma_x(C, D)}{\pi(D(x))}, \end{aligned}$$

where $\pi(D(x)) = \frac{|D(x)|}{|U|}$.

Similarly

$$cov_x(C, D) = \pi_x(C|D).$$

If $C \rightarrow_x D$ is a decision rule then $D \rightarrow_x C$ will be called an *inverse decision rule*. The inverse decision rules can be used to give *explanations (reasons)* for decisions.

Let us observe that

$$cer_x(C, D) = \mu_{D(x)}^C(x) \text{ and } cov_x(C, D) = \mu_{C(x)}^D(x).$$

That means that the certainty factor expresses the degree of membership of x to the decision class $D(x)$, given C , whereas the coverage factor expresses the degree of membership of x to condition class $C(x)$, given D .

27.6 Probabilistic Properties of Decision Tables

Decision tables have important probabilistic properties which are discussed next.

Let $C \rightarrow_x D$ be a decision rule in S and let $\Gamma = C(x)$ and let $\Delta = D(x)$. Then the following properties are valid:

$$\sum_{y \in \Gamma} cer_y(C, D) = 1 \tag{27.1}$$

$$\sum_{y \in \Delta} cov_y(C, D) = 1 \quad (27.2)$$

$$\begin{aligned} \pi(D(x)) &= \sum_{y \in \Gamma} cer_y(C, D) \cdot \pi(C(y)) = \\ &= \sum_{y \in \Gamma} \sigma_y(C, D) \end{aligned} \quad (27.3)$$

$$\begin{aligned} \pi(C(x)) &= \sum_{y \in \Delta} cov_y(C, D) \cdot \pi(D(y)) = \\ &= \sum_{y \in \Delta} \sigma_y(C, D) \end{aligned} \quad (27.4)$$

$$\begin{aligned} cer_x(C, D) &= \frac{cov_x(C, D) \cdot \pi(D(x))}{\sum_{y \in \Delta} cov_y(C, D) \cdot \pi(D(y))} = \\ &= \frac{\sigma_x(C, D)}{\pi(C(x))} \end{aligned} \quad (27.5)$$

$$\begin{aligned} cov_x(C, D) &= \frac{cer_x(C, D) \cdot \pi(C(x))}{\sum_{y \in \Gamma} cer_y(C, D) \cdot \pi(C(y))} = \\ &= \frac{\sigma_x(C, D)}{\pi(D(x))} \end{aligned} \quad (27.6)$$

That is, any decision table, satisfies (1),..., (6). Observe that (3) and (4) refer to the well known *total probability theorem*, whereas (5) and (6) refer to *Bayes' theorem*.

Thus in order to compute the certainty and coverage factors of decision rules according to formulas (5) and (6) it is enough to know the strength (support) of all decision rules only. The strength of decision rules can be computed from data or can be a subjective assessment.

Let us observe that the above properties are valid also for syntactic decision rules, i.e., any decision algorithm satisfies (1),..., (6).

Thus, in what follows, we will use the concept of the decision table and the decision algorithm equivalently.

27.7 Decision Tables and Flow Graphs

With every decision table we associate a *flow graph*, i.e., a directed acyclic graph defined as follows: to every decision rule $C \rightarrow_x D$ we assign a *directed branch* x connecting the *input node* $C(x)$ and the *output node* $D(x)$. Strength

of the decision rule represents a *throughflow* of the corresponding branch. The throughflow of the graph is governed by formulas (1),..., (6).

Formulas (1) and (2) say that an outflow of an input node or an output node is equal to their inflows. Formula (3) states that the outflow of the output node amounts to the sum of its inflows, whereas formula (4) says that the sum of outflows of the input node equals to its inflow. Finally, formulas (5) and (6) reveal how throughflow in the flow graph is distributed between its inputs and outputs.

27.8 Comparison of Bayesian and Rough Set Approach

Now we will illustrate the ideas considered in the previous sections by means of the example considered in section 2. These examples intend to show clearly the difference between "classical" Bayesian approach and that proposed by the rough set philosophy.

Observe that we are not using data to verify prior knowledge, inherently associated with Bayesian data analysis, but the rough set approach shows that any decision table satisfies Bayes' theorem and total probability theorem. These properties form the basis of drawing conclusions from data, without referring either to prior or posterior knowledge.

Example 27.8.1. This example, which is a modification of example 1 given in section 2, will clearly show the different role of Bayes' theorem in classical statistical inference and that in rough set based data analysis.

Let us consider the data table shown in Table 2.

Table 27.2. Data table

	T^+	T^-
D	95	5
\bar{D}	1998	97902

In Table 2, instead of probabilities, like those given in Table 1, numbers of patients belonging to the corresponding classes are given. Thus we start from the original data (not probabilities) representing outcome of the test.

Now from Table 2 we create a decision table and compute strength of decision rules. The results are shown in Table 3.

In Table 3 D is the condition attribute, whereas T is the decision attribute. The decision table is meant to represent a "cause-effect" relation between the disease and result of the test. That is, we expect that the disease causes positive test result and lack of the disease results in negative test result.

Table 27.3. Decision table

<i>fact</i>	<i>D</i>	<i>T</i>	<i>support</i>	<i>strength</i>
1	+	+	95	0.00095
2	-	+	1998	0.01998
3	+	-	5	0.00005
4	-	-	97902	0.97902

The decision algorithm is given below:

- 1') *if (disease, yes) then (test, positive)*
- 2') *if (disease, no) then (test, positive)*
- 3') *if (disease, yes) then (test, negative)*
- 4') *if (disease, no) then (test, negative)*

The certainty and coverage factors of the decision rules for the above decision algorithm are given in Table 4.

Table 27.4. Certainty and coverage

<i>rule</i>	<i>strength</i>	<i>certainty</i>	<i>coverage</i>
1	0.00095	0.95	0.04500
2	0.01998	0.02	0.95500
3	0.00005	0.05	0.00005
4	0.97902	0.98	0.99995

The decision algorithm and the certainty factors lead to the following conclusions:

- 95% persons suffering from the disease have positive test results
- 2% healthy persons have positive test results
- 5% persons suffering from the disease have negative test result
- 98% healthy persons have negative test result

That is to say that if a person has the disease most probably the test result will be positive and if a person is healthy the test result will be most probably negative. In other words, in view of the data there is a causal relationship between the disease and the test result.

The inverse decision algorithm is the following:

- 1) *if (test, positive) then (disease, yes)*
- 2) *if (test, positive) then (disease, no)*

- 3) *if (test, negative) then (disease, yes)*
 4) *if (test, negative) then (disease, no)*

From the coverage factors we can conclude the following:

- 4.5% persons with positive test result are suffering from the disease
- 95.5% persons with positive test result are not suffering from the disease
- 0.005% persons with negative test results are suffering from the disease
- 99.995% persons with negative test results are not suffering from the disease

That means that if the test result is positive it does not necessarily indicate the disease but negative test results most probably (almost for certain) does indicate lack of the disease.

It is easily seen from Table 4 the negative test result almost exactly identifies healthy patients.

For the remaining rules the accuracy is much smaller and consequently test results are not indicating the presence or absence of the disease. \square

It is clearly seen from examples 1 and 2 the difference between Bayesian data analysis and the rough set approach. In the Bayesian inference the data is used to update prior knowledge (probability) into a posterior probability, whereas rough sets are used to understand what the data are telling us.

27.9 Conclusion

From examples 1 and 2 it is easily seen the difference between employing Bayes' theorem in statistical reasoning and the role of Bayes' theorem in rough set based data analysis.

Bayesian inference consists in updating prior probabilities by means of data to posterior probabilities.

In the rough set approach Bayes' theorem reveals data patterns, which are used next to draw conclusions from data, in form of decision rules.

In other words, classical Bayesian inference is based rather on subjective prior probability, whereas the rough set view on Bayes' theorem refers to objective probability inherently associated with decision tables.

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28. Toward Intelligent Systems: Calculi of Information Granules

Andrzej Skowron

Institute of Mathematics, Warsaw University
Banacha 2, 02-097 Warsaw, Poland
skowron@mimuw.edu.pl

We present an approach based on calculi of information granules as a basis for approximate reasoning in intelligent systems. Approximate reasoning schemes are defined by means of information granule construction schemes satisfying some robustness constraints. In distributed environments such schemes are extended to rough neural networks. Problems of learning in rough neural networks from experimental data and background knowledge are discussed. The approach is based on rough mereology.

28.1 Introduction

Computing with Words (CWW) (see, e.g., [28.38], [28.39], [28.40]) is one among a collection of recently emerging computing paradigms. The goal of this new research direction is to build foundations for future intelligent computers and information systems performing computations on words from natural language representing concepts rather than on numbers.

Information granulation belongs to intensively studied topics in soft computing (see, e.g., [28.38], [28.39], [28.40]). One of the recently emerging approaches to deal with information granulation is based on information granule calculi (see, e.g., [28.24], [28.33]). The development of such calculi is important for making progress in many areas like object identification by autonomous systems (see, e.g., [28.3], [28.36]), web mining (see, e.g., [28.8]), spatial reasoning (see, e.g., [28.4]) or sensor fusion (see, e.g., [28.2], [28.16], [28.19]).

One way to achieve CWW is through Granular Computing (GC). The main concepts of GC are related to information granulation and in particular to information granules [28.24].

Any approach to information granulation should make it possible to define complex information granules (e.g., in spatial and temporal reasoning, one should be able to determine if the situation on the road (see Fig. 28.1) is safe on the basis of sensor measurements or to classify situations in complex games, like soccer [28.35]). These complex information granules constitute a form of information fusion. Any calculus of complex information granules should permit to (i) deal with vagueness of information granules, (ii) develop strategies of inducing multi-layered schemes of complex granule construction, (iii) derive robust (stable) information granule construction schemes with respect to deviations of granules from which they are constructed, and (iv)

develop adaptive strategies for reconstruction of induced schemes of complex information granule synthesis.

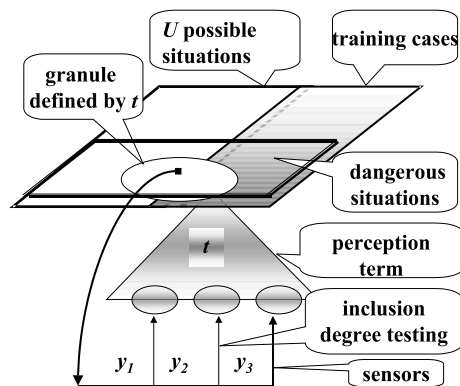


Fig. 28.1. Classification of situations

To deal with vagueness, one can adopt fuzzy set theory [28.37] or rough set theory [28.15] either separately or in combination [28.13]. The second requirement is related to the problem of understanding of reasoning from measurements to perception (see, e.g., [28.40]) and to concept approximation learning in layered learning [28.35] as well as to fusion of information from different sources (see, e.g., [28.38], [28.39], [28.40]). The importance of searching for Approximate Reasoning Schemes (*AR*-schemes, for short) as schemes of new information granule construction, is stressed in rough mereology (see, e.g., [28.20], [28.21], [28.21], [28.22], [28.26], [28.27]). In general, this leads to hierarchical schemes of new information granule construction. This process is closely related to ideas of co-operation, negotiations and conflict resolution in multi-agent systems [28.7]. Among important topics studied in relation to *AR*-schemes are methods for specifying operations on information granules; in particular, for their construction from data and background knowledge, and methods for inducing these hierarchical schemes of information granule construction. One of the possible approaches is to learn such schemes using evolutionary strategies [28.10]. Robustness of the scheme means that any scheme produces rather a higher order information granule that is a clump (e.g., a set) of close information granules rather than a single information granule. Such a clump is constructed by means of the scheme from the Cartesian product of input clumps (e.g., clusters) satisfying some constraints. The input clumps are defined by deviations (up to acceptable degrees) of input information granules.

It is worthwhile to mention that modeling complex phenomena requires to use complex information granules representing local models (perceived by local agents) which next should be fused. This process involves the negotiations between agents [28.7] to resolve contradictions and conflicts in local modeling. This kind of modeling will become more and more important in solving

complex real-life problems which we are unable to model using traditional analytical approaches. If the latter approaches can be applied to modeling of such problems they lead to exact models. However, the necessary assumptions used to build them in case of complex real-life problems are often causing the resulting solutions to be *too far* from reality to be accepted as solutions of such problems.

Let us also observe, using multi-agent terminology, that local agents perform operations on information granules from granule sets that are *understandable* by them. Hence, granules submitted as arguments by other agents should be approximated by means of properly tuned approximation spaces creating interfaces between agents. The process of tuning of the approximation space [28.32], [28.27] parameters in *AR*-schemes corresponds to the tuning of weights in neural networks. The methods for inducing of *AR*-schemes transforming information granules into information granules studied using rough set (see, e.g., [28.15], [28.9]) and rough mereological methods in hybridization with other soft computing approaches create a core for Rough Neurocomputing (RNC) (see, e.g., [28.14], [28.27]). In RNC, computations are performed on information granules.

Another important problem concerns relationships between information granules and words (linguistic terms) in a natural language and also a possibility to use induced *AR*-schemes as schemes matching up to a satisfactory degree reasoning schemes in natural language. Further research in this direction will create strong links between RNC and CWW. The results of such research will be of great importance for many applications (e.g., web mining problems, Fig. 28.2).

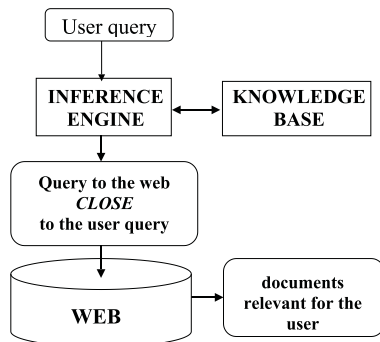


Fig. 28.2. Web mining

RNC is attempting to define information granules using rough sets [28.15], [28.9] and rough mereology (see, e.g., [28.21], [28.21], [28.22], [28.26], [28.27]) introduced to deal with vague concepts in hybridization with other soft computing methods like neural networks [28.29], fuzzy sets [28.13], [28.37], [28.39]

and evolutionary programming [28.14], [28.10]. The methods based on the above mentioned approaches can be used for constructing of more complex information granules by means of schemes analogous to neural networks.

We outline a rough neurocomputing model as a basis for granular computing.

28.2 AR-Schemes

AR-schemes are the basic constructs used in RNC. We assume each agent ag from a given collection Ag of agents [28.7] is equipped with a system of information granules $S(ag)$ specifying information granules the agent ag is perceiving and the inclusion (or closeness) relations to a degree used by ag to measure the degree of inclusion (or closeness) between information granules. A formal definition of information granule system the reader can find, e.g., in [28.31]. Using such system $S(ag)$ the agent ag creates a representation for all components of $S(ag)$. The details of such representation the reader can find, e.g., in [28.22], [28.24]. From such representations agents are able to extract local schemes of approximate reasoning called productions. Algorithmic methods for extracting such productions from data are discussed in [28.21], [28.30], [28.34], [28.17], [28.18]. The left hand side of each production is (in the simplest case) of the form $(st_1(ag), (\epsilon_1^{(1)}, \cdot, \epsilon_r^{(1)}), \cdot, (st_k(ag), (\epsilon_1^{(k)}, \cdot, \epsilon_r^{(k)}))$ and the right hand side is of the form $(st(ag), (\epsilon_1, \cdot, \epsilon_r))$ for some positive integers k, r .

Such production represents an information about an operation o which can be performed by the agent ag . In the production k denotes the arity of operation. The operation o represented by the production is transforming standard (prototype) input information granules $st_1(ag), \dots, st_k(ag)$ into the standard (prototype) information granule $st(ag)$. Moreover, if input information granules g_1, \dots, g_k are close to $st_1(ag), \dots, st_k(ag)$ to degrees $\epsilon_j^{(1)}, \dots, \epsilon_j^{(k)}$ then the result of the operation o on information granules g_1, \dots, g_k is close to the standard $st(ag)$ to a degree at least ϵ_j where $1 \leq j \leq k$. Standard (prototype) granules can be interpreted in different ways. In particular they can correspond to concept names in natural language.

The described above productions are basic components of reasoning system over an agent set Ag . An important property of such productions is that they are expected to be discovered from available experimental data and background knowledge. Let us also observe that the degree structure is not necessarily restricted to reals from the interval $[0, 1]$. The inclusion degrees can have a structure of complex information granules used to represent the degree of inclusion. It is worthwhile to mention that the productions can also be interpreted as a constructive description of some operations on fuzzy sets. The methods for such constructive description are based on rough sets and Boolean reasoning (see, e.g., [28.9], [28.15]).

AR-schemes can be treated as derivations obtained by using productions from different agents. The relevant derivations defining *AR*-schemes are satisfying so called robustness (or stability) condition. It means that at any node of derivation the inclusion (or closeness) degree of constructed granule to the prototype (standard) granule is higher than required by the production to which the result should be sent. This makes it possible to obtain a sufficient robustness condition for the whole derivations. For details the reader is referred to, e.g., [28.22], [28.24], [28.25], [28.26]. In case where standards are interpreted as concept names in natural language and there is given a reasoning scheme in natural language over the standard concepts the corresponding *AR*-scheme represents a cluster of reasoning (constructions) approximately following (by means of other information granule systems) the reasoning in natural language.

28.3 Rough Neural Networks

We extend *AR*-schemes for synthesis of complex objects (or granules) developed in [28.24] and [28.22] by adding one important component. As a result we obtain granule construction schemes that can be treated as a generalization of neural network models. The main idea is that granules sent by one agent to another are not, in general, exactly understandable by the receiving agent. This is because these agents are using different languages and usually does not exist any translation (from the sender language to the receiver language) preserving exactly semantical meaning of formulas. Hence, it is necessary to construct interfaces that will make it possible to understand received granules approximately. These interfaces can be, in the simplest case, constructed on the basis of information exchanged by agents and stored in the form of decision data tables. From such tables the approximations of concepts can be constructed using rough set approach [28.33]. In general, it is a complex process because a high quality approximation of concepts can be often obtained only in dialog (involving negotiations, conflict resolutions and cooperation) among agents. In this process the approximation can be constructed gradually when dialog is progressing. In our model we assume that for any n -ary operation $o(ag)$ of an agent ag there are approximation spaces $AS_1(o(ag), in), \dots, AS_n(o(ag), in)$ which will filter (approximate) the granules received by the agent for performing the operation $o(ag)$. In turn, the granule sent by the agent after performing the operation is filtered (approximated) by the approximation space $AS(o(ag), out)$. These approximation spaces are parameterized. The parameters are used to optimize the size of neighborhoods in these spaces as well as the inclusion relation [28.26]. A granule approximation quality is taken as the optimization criterion. Approximation spaces attached to any operation of ag correspond to neuron weights in neural networks whereas the operation performed by the agent ag on information granules corresponds to the operation realized on vectors of

real numbers by the neuron. The generalized scheme of agents is returning a granule in response to input information granules. It can be for example a cluster of elementary granules. Hence, our schemes realize much more general computations than neural networks operating on vectors of real numbers.

We call extended schemes for complex object construction *rough neural networks* (for complex object construction). The problem of deriving such schemes is closely related to perception (see, e.g., [28.1], [28.40]). The stability of such networks corresponds to the resistance to noise of classical neural networks.

Let us observe that in our approach the deductive systems are substituted by productions systems of agents linked by approximation spaces, communication strategies and mechanism of derivation of *AR*-schemes. This revision of classical logical notions seems to be important for solving complex problems in distributed environments.

28.4 Decomposition of Information Granules

Information granule decomposition methods are important components of methods for inducing of *AR*-schemes from data and background knowledge. Such methods are used to extract from data, local decomposition schemes called productions [28.25]. The *AR*-schemes are constructed by means of productions. The decomposition methods are based on searching for the parts of information granules that can be used to construct relevant higher level patterns matching up to a satisfactory degree the target granule.

One can distinguish two kinds of parts (represented, e.g., by sub-formulas or sub-terms) of *AR*-schemes. Parts of the first type are represented by expressions from a language, called the *domestic* language L_d , that has known semantics (consider, for example, semantics defined in a given information system [28.15]). Parts of the second type of *AR*-scheme are from a language, called *foreign* language L_f (e.g., natural language), that has semantics definable only in an approximate way (e.g., by means of patterns extracted using rough, fuzzy, rough–fuzzy or other approaches). For example, the parts of the second kind of scheme can be interpreted as soft properties of sensor measurements [28.3].

For a given expression e , representing a given scheme that consists of sub-expressions from L_f first it is necessary to search for relevant approximations in L_d of the foreign parts from L_f and next to derive global patterns from the whole expression after replacing the foreign parts by their approximations. This can be a multilevel process, i.e., we are facing problems of discovered pattern propagation through several domestic-foreign layers.

Productions from which *AR*-schemes are built can be induced from data and background knowledge by pattern extraction strategies. Let us consider some of such strategies. The first one makes it possible to search for relevant approximations of parts using the rough set approach. This means that each

part from L_f can be replaced by its lower or upper approximation with respect to a set B of attributes. The approximation is constructed on the basis of relevant data table [28.15], [28.9]. With the second strategy parts from L_f are partitioned into a number of sub-parts corresponding to cuts (or the set theoretical differences between cuts) of fuzzy sets representing vague concepts and each sub-part is approximated by means of rough set methods. The third strategy is based on searching for patterns sufficiently included in foreign parts. In all cases, the extracted approximations replace foreign parts in the scheme and candidates for global patterns are derived from the scheme obtained after the replacement. Searching for relevant global patterns is a complex task because many parameters should be tuned, e.g., the set of relevant features used in approximation, relevant approximation operators, the number and distribution of objects from the universe of objects among different cuts and so on. One can use evolutionary techniques [28.10] in searching for (semi-) optimal patterns in the decomposition.

It has been shown that the decomposition strategies can be based on the developed rough set methods for decision rules generation and Boolean reasoning [28.21], [28.12], [28.17], [28.33]. In particular, methods for decomposition based on background knowledge can be developed [28.30], [28.18].

Conclusions. We have discussed a methodology for synthesis of *AR*-schemes and rough neural networks. For more details the reader is referred to [28.21], [28.22], [28.23], [28.24], [28.26], [28.27], [28.32], [28.33], [28.34].

We enclose a list of research directions related to the synthesis and analysis of *AR*-schemes and rough neural networks.

1. *Developing foundations for information granule systems.* Certainly, still more work is needed to develop solid foundations for synthesis and analysis of information granule systems. In particular, methods for construction of hierarchical information granule systems, and methods for representation of such systems should be developed.
2. *Algorithmic methods for inducing parameterized productions.* Some methods have already been reported such as discovery of rough mereological connectives from data (see, e.g., [28.21]) or methods based on decomposition (see, e.g., [28.22], [28.30], [28.34], [28.17]). However, these are only initial steps toward algorithmic methods for inducing of parameterized productions from data. One interesting problem is to determine how such productions can be extracted from data and background knowledge. A method in this direction has been proposed in [28.3].
3. *Algorithmic methods for synthesis of AR-schemes.* It was observed (see, e.g., [28.22], [28.27]) that problems of negotiations and conflict resolutions are of great importance for synthesis of *AR*-schemes. The problem arises, e.g., when we are searching in a given set of agents for a granule sufficiently included or close to a given one. These agents, often working with different systems of information granules, can derive different gra-

nules and their fusion will be necessary to obtain the relevant output granule. In the fusion process, the negotiations and conflict resolutions are necessary. Much more work should be done in this direction by using the existing results on negotiations and conflict resolution. In particular, Boolean reasoning methods seem to be promising ([28.22]) for solving such problems. Another problem is related to the size of production sets. These sets can be of large size and it is important to develop learning methods for extracting *small* candidate production sets in the process of extension of temporary derivations out of huge production sets. For solving this kind of problems methods for clustering of productions should be developed to reduce the size of production sets. Moreover, dialog and cooperation strategies between agents can help to reduce the search space in the process of *AR*-scheme construction from productions.

4. *Algorithmic methods for learning in rough neural networks.* A basic problem in rough neural networks is related to selecting relevant approximation spaces and to parameter tuning. One can also look up to what extent the existing methods for classical neural methods can be used for learning in rough neural networks. However, it seems that new approach and methods for learning of rough neural networks should be developed to deal with real-life applications. In particular, it is due to the fact that high quality approximations of concepts can be often obtained only through dialog and negotiations processes among agents in which gradually the concept approximation is constructed. Hence, for rough neural networks learning methods based on dialog, negotiations and conflict resolutions should be developed. In some cases, one can use directly rough set and Boolean reasoning methods (see, e.g., [28.33]). However, more advanced cases need new methods. In particular, hybrid methods based on rough and fuzzy approaches can bring new results [28.13].
5. *Fusion methods in rough neural neurons.* A basic problem in rough neurons is fusion of the inputs (information) derived from information granules. This fusion makes it possible to contribute to the construction of new granules. In the case where the granule constructed by a rough neuron consists of characteristic signal values made by relevant sensors, a step in the direction of solving the fusion problem can be found in [28.19], [28.6].

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29. Soft Computing Pattern Recognition: Principles, Integrations, and Data Mining

Sankar K. Pal

Machine Intelligence Unit
Indian Statistical Institute
Calcutta 700035, India
sankar@isical.ac.in

Relevance of fuzzy logic, artificial neural networks, genetic algorithms and rough sets to pattern recognition and image processing problems is described through examples. Different integrations of these soft computing tools are illustrated. Evolutionary rough fuzzy network which is based on modular principle is explained, as an example of integrating all the four tools for efficient classification and rule generation, with its various characteristics. Significance of soft computing approach in data mining and knowledge discovery is finally discussed along with the scope of future research.

29.1 Introduction

Soft computing is a consortium of methodologies which work synergistically and provides in one form or another flexible information processing capabilities for handling real life ambiguous situations. Its aim is to exploit the tolerance for imprecision, uncertainty, approximate reasoning and partial truth in order to achieve *tractability, robustness, low cost solutions, and close resemblance to human like decision making*. In other words, it provides the foundation for the conception and design of high MIQ (Machine IQ) systems, and therefore forms the basis of future generation computing systems. At this juncture, Fuzzy Logic (FL), Rough Sets (RS), Artificial Neural Networks (ANN) and Genetic Algorithms (GA) are the principal components where FL provides algorithms for dealing with imprecision and uncertainty arising from vagueness rather than randomness, RS for handling uncertainty arising from limited discernibility of objects, ANN the machinery for learning and adaptation, and GA for optimization and searching [29.1, 29.2].

Machine recognition of patterns [29.3, 29.4] can be viewed as a two-fold task, consisting of learning the invariant and common properties of a set of samples characterizing a class, and of deciding that a new sample is a possible member of the class by noting that it has properties common to those of the set of samples. Therefore, the task of pattern recognition by a computer can be described as a transformation from the measurement space M to the feature space F and finally to the decision space D . Depending on the type of input patterns, one may have speech recognition system, image recognition or vision system, medical diagnostic system etc.

In this article we first describe the relevance of different soft computing tools to pattern recognition problems with examples. Different integration among them are then described. As an example we explain an evolutionary rough fuzzy MLP, which has been designed based on modular concept for pattern classification and rule generation. Finally the significance of soft computing in data mining and knowledge discovery is discussed.

29.2 Relevance of Fuzzy Set Theory in Pattern Recognition

Fuzzy sets were introduced in 1965 by Zadeh [29.5] as a new way to represent vagueness in everyday life. They are generalizations of conventional (crisp) set theory. Conventional sets contain objects that satisfy precise properties required for membership. Fuzzy sets, on the other hand, contain objects that satisfy imprecisely defined properties to varying degrees. A fuzzy set A of the universe X is defined as a collection of ordered pairs

$$A = \{(\mu_A(x), x), \forall x \in X\}$$

where $\mu_A(x)$, ($0 \leq \mu_A(x) \leq 1$) gives the degree of belonging of the element x to the set A or the degree of possession of an imprecise property represented by A . Different aspects of fuzzy set theory including membership functions, basic operations and uncertainty measures can be found in [29.5, 29.6].

In this section we explain some of the uncertainties which one often encounters while designing a pattern recognition system and the relevance of fuzzy set theory in handling them. Let us consider, first of all, the case of processing and recognition of a gray-tone image pattern. Conventional approaches to image analysis and recognition [29.7, 29.8] consist of segmenting the image into meaningful regions, extracting their edges and skeletons, computing various features (e.g., area, perimeter, centroid etc.) and primitives (e.g., line, corner, curve etc.) of and relationships among the regions, and finally, developing decision rules and grammars for describing, interpreting and/or classifying the image and its sub-regions. In a conventional system each of these operations involves crisp decisions (i.e., yes or no, black or white, 0 or 1) to make regions, features, primitives, properties, relations and interpretations crisp.

Since the regions in an image are not always crisply defined, uncertainty can arise within every phase of the aforesaid tasks. Any decision made at a particular level will have an impact on all higher level activities. An image recognition system should have sufficient provision for representing and manipulating the uncertainties involved at every processing stage; i.e., in defining image regions, features and relations among them, so that the system retains as much of the 'information content' of the data as possible. If this is done, the ultimate output (result) of the system will possess minimal uncertainty

(and unlike conventional systems, it may not be biased or affected as much by lower level decision components).

In Short, gray information is expensive and informative. Once it is thrown away, there is no way to get it back. Therefore one should try to retain this information as long as possible throughout the decision making tasks for its full use. When it is required to make a crisp decision at the highest level one can always through away or ignore this information.

Let us now consider the case of a decision-theoretic approach to pattern classification. With the conventional probabilistic and deterministic classifiers [29.3, 29.4], the features characterizing the input patterns are considered to be quantitative (numeric) in nature. The patterns having imprecise or incomplete information are usually ignored or discarded from their designing and testing processes. The impreciseness (or ambiguity) may arise from various causes. For example, instrumental error or noise corruption in the experiment may lead to only partial or partially reliable information being available on a feature measurement F . Again, in some cases it may become convenient to use linguistic variables and hedges. In such cases, it is not appropriate to give exact representation to uncertain feature data. Rather, it is reasonable to represent uncertain feature information by fuzzy subsets.

Again, uncertainty in classification or clustering of patterns may arise from the overlapping nature of the various classes. This overlapping may result from fuzziness or randomness. In the conventional technique, it is usually assumed that a pattern may belong to only one class, which is not necessarily true in real life applications. A pattern can and should be allowed to have degrees of membership in more than one class. It is, therefore, necessary to convey this information while classifying a pattern or clustering a data set.

From the aforementioned examples, we see that the concept of fuzzy sets can be used at the *feature level* in representing input data as an array of membership values denoting the degree of possession of certain properties, in representing linguistically phrased input features for their processing, in weakening the strong commitments for extracting ill-defined image regions, properties, primitives, and relations among them, and at the *classification level*, for representing class membership of objects in terms of membership values. *In other words, fuzzy set theory provides a notion of embedding: We find a better solution to a crisp problem by looking in a large space at first, which has different (usually less) constraints and therefore allows the algorithm more freedom to avoid errors forced by commission to hard answers in intermediate stages.*

The capability of fuzzy set theory in pattern recognition problems has been reported adequately since late sixties. A cross-section of the advances with applications is available in [29.6, 29.2, 29.9].

29.3 Relevance of Neural Network Approaches

Neural network (*NN*) models [29.10, 29.11] try to emulate the biological neural network/nervous system with electronic circuitry. *NN* models have been studied for many years with the hope of achieving human-like performance (artificially), particularly in the field of pattern recognition, by capturing the key ingredients responsible for the remarkable capabilities of the human nervous system. Note that these models are extreme simplifications of the actual human nervous system.

NNs are designated by the network topology, connection strength between pairs of neurons (called weights), node characteristics and the status updating rules. Node characteristics mainly specify the primitive types of operations it can perform, like summing the weighted inputs coming to it and then amplifying it or doing some fuzzy aggregation operations. The updating rules may be for weights and/or states of the processing elements (neurons). Normally an objective function is defined which represents the complete status of the network and the set of minima of it corresponds to the set of stable states of the network. Since there are interactions among the neurons the collective computational property inherently reduces the computational task and makes the system fault tolerant. Thus *NN* models are also suitable for tasks where collective decision making is required. Hardware implementations of neural networks are also attempted.

Neural network based systems are usually reputed to enjoy the following major characteristics:

- *adaptivity*- adjusting the connection strengths to new data/information,
- *speed*- due to massively parallel architecture,
- *robustness*- to missing, confusing, ill-defined/noisy data,
- *ruggedness*- to failure of components,
- *optimality*- as regards error rates in performance.

For any pattern recognition system, one desires to achieve the above mentioned characteristics. More over, there exists some direct analogy between the working principles of many pattern recognition tasks and neural network models. For example, image processing and analysis in the spatial domain mainly employ simple arithmetic operations at each pixel site in parallel. These operations usually involve information of neighboring pixels (co-operative processing) in order to reduce the local ambiguity and to attain global consistency. An objective measure is required (representing the overall status of the system), the optimum of which represents the desired goal. The system thus involves collective decisions. On the other hand, we notice that neural network models are also based on parallel and distributed working principles (all neurons work in parallel and independently). The operations performed at each processor site are also simpler and independent of the others. The overall status of a neural network can also be measured.

Again, the task of recognition in a real-life problem involves searching a complex decision space. This becomes more complicated particularly when there is no prior information on class distribution. Neural network based systems use adaptive learning procedures, learn from examples and attempt to find a useful relation between input and output, however complex it may be, for decision-making problems. Neural networks are also reputed to model complex non-linear boundaries and to discover important underlying regularities in the task domain. These characteristics demand that methods are needed for constructing and refining neural network models for various recognition tasks. *In short, neural networks are natural classifiers having resistance to noise, tolerance to distorted images/patterns (ability to generalize), superior ability to recognize partially occluded or degraded images/overlapping pattern classes or classes with highly nonlinear boundaries, and potential for parallel processing.*

29.4 Genetic Algorithms for Pattern Recognition

Genetic Algorithms (GAs) [29.12, 29.13, 29.14, 29.15] are adaptive computational procedures modeled on the mechanics of natural genetic systems. They express their ability by efficiently exploiting the historical information to speculate on new offspring with expected improved performance [29.12]. GAs are executed iteratively on a set of coded solutions, called *population*, with three basic operators: *selection/reproduction*, *crossover* and *mutation*. They use only the payoff (objective function) information and probabilistic transition rules for moving to the next iteration. They are different from most of the normal optimization and search procedures in four ways:

- GAs work with the coding of the parameter set, not with the parameter themselves.
- GAs work simultaneously with multiple points, and not a single point.
- GAs search via sampling (a blind search) using only the payoff information.
- GAs search using stochastic operators, not deterministic rules.

One may note that the methods developed for pattern recognition and image processing are usually problem dependent. Moreover, many tasks involved in the process of analyzing/identifying a pattern need appropriate parameter selection and efficient search in complex spaces in order to obtain optimal solutions. This makes the process not only computationally intensive, but also leads to a possibility of losing the exact solution. Therefore, the application of genetic algorithms for solving certain problems of pattern recognition, which need optimization of computation requirements, and robust, fast and close approximate solution, appears to be appropriate and natural [29.13].

29.5 Integration and Hybrid Systems

Integration of the individual soft computing tools help in designing hybrid systems which are more versatile and efficient compared to stand alone use of the tools. The most visible integration in soft computing community is that of neural networks and fuzzy sets [29.2]. Neuro-fuzzy systems has been successfully developed for decision making, pattern recognition and image processing tasks. The hybridization falls in two major categories: a neural network equipped with the capability of handling fuzzy information (termed fuzzy neural network) to augment its application domain, and a fuzzy system augmented by neural networks to enhance some of its characteristics like flexibility, speed, adaptivity, learning (termed neural-fuzzy systems). Both the classes of hybridisation and their application to various pattern recognition problem are described in [29.2].

There are some applications where the integration of GAs with fuzzy sets and ANNs is found to be effective. For example GAs are found sometimes essential for overcoming some of the limitations of fuzzy set theory, specifically to reduce the 'subjective' nature of membership functions. Note that the other way of integration, i.e., incorporating the concept of fuzziness into GAs has not been tried seriously. Synthesis of ANN architectures can be done using GAs as an example of neuro-genetic systems. Such an integration may help in designing optimum ANN architecture with appropriate parameter sets. Methods for designing neural network architectures using GAs are primarily divided into two parts. In one part the GA replaces the learning method to find appropriate connection weights of some predefined architecture. In another part, GAs are used to find the architecture itself and it is then evaluated using some learning algorithms. Literature is also available on integration of fuzzy sets, neural networks and genetic algorithms [29.2, 29.16, 29.17].

The theory of rough sets [29.18] has emerged as another major mathematical approach for managing uncertainty that arises from inexact, noisy, or incomplete information. It is turning out to be methodologically significant to the domains of artificial intelligence and cognitive sciences, especially in the representation of and reasoning with vague and/or imprecise knowledge, data classification, data analysis, machine learning, and knowledge discovery [29.19].

Recently, rough sets have been integrated with both fuzzy sets and neural networks. Several rough-fuzzy hybrid systems are discussed in [29.2]. In the framework of rough-neuro integration [29.20], two broad approaches are available, namely, use of roughs set for encoding weights of knowledge based networks [29.21], and designing neural network architectures which incorporate roughness in the neuronal level. Genetic algorithms have also been used for fast generation of rough set reducts from an indiscernibility matrix.

In the next section we describe, as an example, a methodology for integrating all the four soft computing tools, *viz.*, fuzzy sets, ANN, rough sets

and GAs for classification and rule generation. Here rough sets are used to encode domain knowledge in network parameters of a fuzzy MLP. GAs are used to evolve the optimal architecture based on modular concept.

29.6 Evolutionary Rough Fuzzy MLP

The evolutionary rough fuzzy MLP utilises the concept of modular learning for better integration and performance enhancement [29.22]. The knowledge flow structure of evolutionary rough fuzzy MLP is illustrated in Figure 29.1. Here each of the soft computing tools act synergistically to contribute to the final performance of the system as follows. Rough set rules are used for extracting crude domain knowledge, which when encoded in a fuzzy MLP not only results in fast training of the network, but also automatic determination of the network size. The GA operators are adaptive and use the domain knowledge extracted with rough sets for even faster learning. The fuzziness incorporated at the input and outputs helps in better handling of uncertainties and overlapping classes. The nature of integration is illustrated in Figure 29.2.

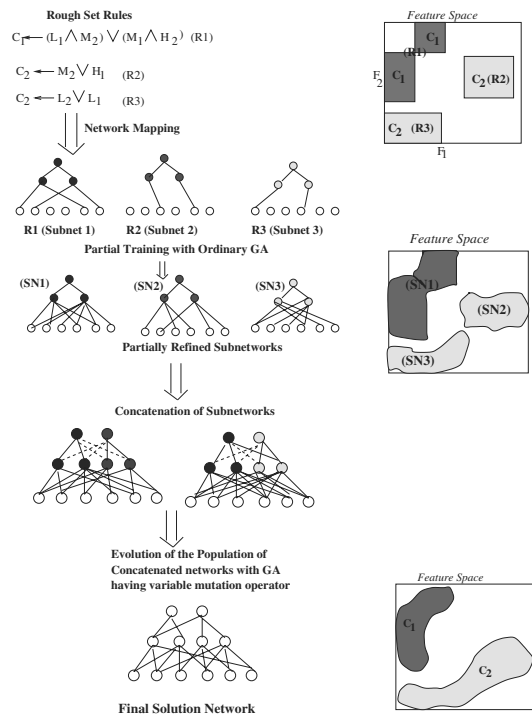


Fig. 29.1. Knowledge Flow in Modular Rough Fuzzy MLP

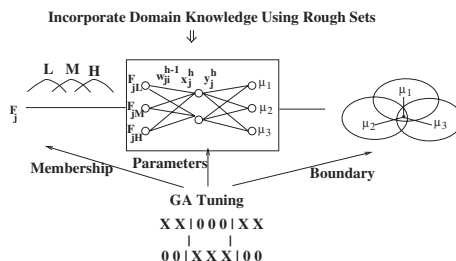


Fig. 29.2. Components of the Modular Rough-fuzzy MLP

The evolutionary modular rough fuzzy MLP has been applied to a number of real world problems like speech recognition and medical diagnosis. In case of speech recognition [29.22], the system is found to correctly classify 84% of the samples, while the fuzzy MLP correctly classifies only 78% and the MLP only 59%. The system also gained in computation time significantly. For determining the stages of Cervical Cancer [29.22], the system provides results identical to that of medical experts in 83% of the cases. In other cases also the stagings were close. In addition to the above performance logical rules were extracted from the trained system. It was found that the rules coincided with the guidelines adopted by medical practitioners for staging. In the rough fuzzy MLP, the final network has a structure imposed on the weights. Hence, crisp logical rules can be easily extracted from the networks. This makes the system suitable for Knowledge Discovery in Databases. The rules obtained are found to be superior to those of several popular methods, as measured with some quantitative indices. For example, on the speech recognition data, the rules obtained using the modular rough-fuzzy MLP have an accuracy of 81.02% with 10 rules, while the popular C4.5 rule generation algorithm have accuracy of 75.00% using 16 rules. Fraction of samples which are ‘uncovered’ by the rules obtained by us is only 3.10%, whereas the C4.5 rules have 7.29% uncovered samples. The ‘confusion index’ is also low for the proposed method (1.4) compared to C4.5 (2.0).

29.7 Data Mining and Knowledge Discovery

In recent years, the rapid advances being made in computer technology have ensured that large sections of the world population have been able to gain easy access to computers on account of falling costs worldwide, and their use is now commonplace in all walks of life. Government agencies, scientific, business and commercial organizations are routinely using computers not just for computational purposes but also for storage, in massive databases, of the immense volumes of data that they routinely generate, or require from other sources. Large-scale computer networking has ensured that such data has become accessible to more and more people. In other words, we are in the

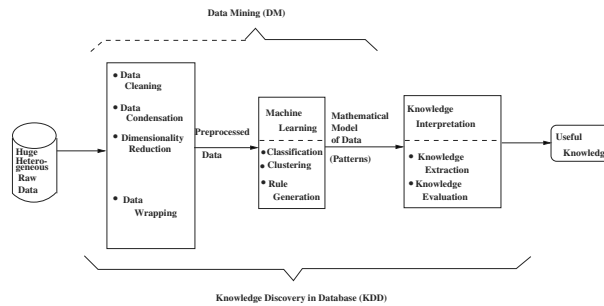


Fig. 29.3. Block diagram for Knowledge Discovery in Databases (KDD)

midst of an information explosion, and there is urgent need for methodologies that will help us bring some semblance of order into the phenomenal volumes of data that can readily be accessed by us with a few clicks of the keys of our computer keyboard. Traditional statistical data summarization and database management techniques are just not adequate for handling data on this scale, and for extracting intelligently, information or, rather, knowledge that may be useful for exploring the domain in question or the phenomena responsible for the data, and providing support to decision-making processes. This quest had thrown up some new phrases, for example, *data mining* and *knowledge discovery in databases (KDD)*, which are perhaps self-explanatory, but will be briefly discussed in the next few paragraphs. Their relationship with the discipline of pattern recognition will also be examined.

The massive databases that we are talking about are generally characterized by the presence of not just numeric, but also textual, symbolic, pictorial and aural data. They may contain redundancy, errors, imprecision, and so on. KDD is aimed at discovering natural structures within such massive and often heterogeneous data. Therefore PR plays a significant role in KDD process. However, KDD is being visualized as not just being capable of knowledge discovery using generalizations and magnifications of existing and new pattern recognition algorithms, but also the adaptation of these algorithms to enable them to process such data, the storage and accessing of the data, its preprocessing and cleaning, interpretation, visualization and application of the results, and the modeling and support of the overall human-machine interaction. What really makes KDD feasible today and in the future is the rapidly falling cost of computation, and the simultaneous increase in computational power, which together make possible the routine implementation of sophisticated, robust and efficient methodologies hitherto thought to be too computation-intensive to be useful. A block diagram of KDD is given in Figure 29.3.

Data mining is that part of knowledge discovery which deals with the process of identifying valid, novel, potentially useful, and ultimately understandable patterns in data, and excludes the knowledge interpretation part

of KDD. Therefore, as it stands now, data mining can be viewed as applying PR and machine learning principles in the context of voluminous, possibly heterogeneous data sets. Furthermore, soft computing-based (involving fuzzy sets, neural networks, genetic algorithms and rough sets) PR methodologies and machine learning techniques seem to hold great promise for data mining. The motivation for this is provided by their ability to handle imprecision, vagueness, uncertainty, approximate reasoning and partial truth and lead to tractability, robustness and low-cost solutions. In this context, case-based reasoning [29.17], which is a novel Artificial Intelligence (AI) problem-solving paradigm, has a significant role to play, as is evident from the recent book edited by Pal, Dillon and Yeung [29.17].

Some of the challenges that researchers in this area are likely to deal with, include those posed by massive data sets and high dimensionality, nonstandard and incomplete data, and overfitting. The focus is most likely to be on aspects like user interaction, use of prior knowledge, assessment of statistical significance, learning from mixed media data, management of changing data and knowledge, integration of tools, ways of making knowledge discovery more understandable to humans by using rules, visualization, *etc.*, and so on. We believe the next decade will bear testimony to this.

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30. Identifying Upper and Lower Possibility Distributions with Rough Set Concept

P. Guo¹ and Hideo Tanaka²

¹ Faculty of Economics, Kagawa University, Takamatsu, Kagawa, 760-8523 Japan, guo@ec.kagawa-u.ac.jp

² Toyohashi Sozo College, 20-1 Matsushita, Ushikawacho, Toyohashi, 440-8511 Japan, tanakah@sozo.ac.jp

30.1 Concepts of Upper and Lower Possibility Distributions

Knowledge from one expert can be represented by a data set $\{(\mathbf{x}_i, h_i) | i=1, \dots, m\}$ where $\mathbf{x}_i = [x_{i1}, \dots, x_{in}]^t$ is an n -dimensional vector to characterize some specified event, h_i is an associated possibility grade given by an expert to reflect his judgement on what the possibility grade of the i th sample is for this event, and m is the number of samples. The data set (\mathbf{x}_i, h_i) ($i=1, \dots, m$) can be approximated by a dual data sets (\mathbf{x}_i, h_{li}) and (\mathbf{x}_i, h_{ui}) ($i=1, \dots, m$) with the condition $h_{li} \leq h_i \leq h_{ui}$. Assume that the values h_{li} and h_{ui} are from a class of the functions $G(\mathbf{x}, \theta)$ with parameter vector θ . Let $G(\mathbf{x}_i, \theta_l)$ and $G(\mathbf{x}_i, \theta_u)$ correspond to h_{li} and h_{ui} ($i=1, \dots, m$), respectively and simply denote as $\pi_l(\mathbf{x}_i)$ and $\pi_u(\mathbf{x}_i)$. Given the data set (\mathbf{x}_i, h_i) ($i=1, \dots, m$), the objective of estimation is to obtain two optimal parameter vectors θ_l^* and θ_u^* from the parameter space to approximate (\mathbf{x}_i, h_i) from upper and lower directions according to some given measure. Moreover, the dual optimal parameter vectors (θ_l^*, θ_u^*) make the relation $G(\mathbf{x}, \theta_l^*) \leq G(\mathbf{x}, \theta_u^*)$ hold for any arbitrary n -dimensional vector \mathbf{x} .

Suppose that the function $G(\mathbf{x}, \theta)$ is an exponential function $\exp\{-(\mathbf{x} - \mathbf{a})^t \mathbf{D}_A^{-1} (\mathbf{x} - \mathbf{a})\}$, simply denoted as $(\mathbf{a}, \mathbf{D}_A)_e$. Then the following formulas hold.

$$\pi_l(\mathbf{x}_i) = \exp\{-(\mathbf{x}_i - \mathbf{a})^t \mathbf{D}_l^{-1} (\mathbf{x}_i - \mathbf{a})\}, \quad i=1, \dots, m, \quad (1)$$

$$\pi_u(\mathbf{x}_i) = \exp\{-(\mathbf{x}_i - \mathbf{a})^t \mathbf{D}_u^{-1} (\mathbf{x}_i - \mathbf{a})\}, \quad i=1, \dots, m, \quad (2)$$

$$\pi_l(\mathbf{x}_i) \leq h_i \leq \pi_u(\mathbf{x}_i) \quad \text{and} \quad \pi_l(\mathbf{x}) \leq \pi_u(\mathbf{x}), \quad i=1, \dots, m, \quad (3)$$

where $\mathbf{a}=[a_1, a_2, \dots, a_n]^t$ is a center vector, \mathbf{D}_u and \mathbf{D}_l are positive definite matrices, denoted as $\mathbf{D}_u > 0$ and $\mathbf{D}_l > 0$, respectively. It can be seen that in the above exponential function, vector \mathbf{a} and matrices \mathbf{D}_u and \mathbf{D}_l are parameters to be solved. Different parameters \mathbf{a} , \mathbf{D}_u and \mathbf{D}_l lead to different values $\pi_l(\mathbf{x}_i)$ and $\pi_u(\mathbf{x}_i)$ which approximate the given possibility degree h_i of \mathbf{x}_i to the different extent.

Definition 1. Given the formulas (1), (2) and (3), the fitness of approximation based on parameters \mathbf{a} , \mathbf{D}_u and \mathbf{D}_l , denoted as β , is defined as follows:

$$\beta = \sqrt[m]{\prod_{i=1}^m \frac{\pi_l(\mathbf{x}_i)}{\pi_u(\mathbf{x}_i)}}. \quad (4)$$

It is known from Definition 1 that the higher the parameter β is, the closer to h_i values $\pi_l(\mathbf{x}_i)$ and $\pi_u(\mathbf{x}_i)$ are from lower and upper directions, respectively.

$\prod_{i=1}^m \pi_l(\mathbf{x}_i)$ and $\prod_{i=1}^m \pi_u(\mathbf{x}_i)$ can be regarded as likelihood functions for lower and upper possibility distributions.

Definition 2. Denote the optimal solutions of \mathbf{a} , \mathbf{D}_u and \mathbf{D}_l as \mathbf{a}_* , \mathbf{D}_{*u} and \mathbf{D}_{*l} , respectively, which maximize β with the constraint (3). The following functions

$$\pi_{*l}(\mathbf{x}) = \exp\{-(\mathbf{x}-\mathbf{a}_*)^t \mathbf{D}_{*l}^{-1}(\mathbf{x}-\mathbf{a}_*)\} \quad (5)$$

$$\pi_{*u}(\mathbf{x}) = \exp\{-(\mathbf{x}-\mathbf{a}_*)^t \mathbf{D}_{*u}^{-1}(\mathbf{x}-\mathbf{a}_*)\} \quad (6)$$

are called lower and upper exponential possibility distributions of the possibility vector \mathbf{X} , respectively. For simplicity afterwards we write $\pi_u(\mathbf{x})$ and $\pi_l(\mathbf{x})$ instead of $\pi_{*u}(\mathbf{x})$ and $\pi_{*l}(\mathbf{x})$.

30.2 Comparison of Dual Possibility Distributions with Dual Approximations in Rough Sets Theory

Rough sets theory has been proposed by Pawlak and extensively applied to classification problems, machine learning, and decision analysis etc. [1, 2]. For comparing the dual possibility distributions with the rough sets, the basic notions of rough sets are introduced below.

Let U be the universe of objects and R be an equivalence relation in U . Then by U/R we mean the family of all equivalence class of R . Equivalence classes of the relation R are called elementary sets. Any finite union of elementary sets is said to be a definable set. Given a set Z , the upper and lower approximations of Z , de-

noted as $R^*(Z)$ and $R_*(Z)$, respectively are two definable sets defined as follows:

$$R^*(Z) = \bigcup \{Y \in U / R : Y \cap Z \neq \emptyset\}, \quad (7)$$

$$R_*(Z) = \bigcup \{Y \in U / R : Y \subseteq Z\} \quad (8)$$

where \emptyset is the empty set.

It can be seen that the upper approximation of Z is defined as the least definable set containing the set Z and the lower approximation of Z is defined as the greatest definable set contained in Z so that the condition $R^*(Z) \supseteq R_*(Z)$ holds. An accuracy measure of a set Z , denoted as $\alpha(Z)$, is defined as

$$\alpha(Z) = \frac{\text{Card}(R_*(Z))}{\text{Card}(R^*(Z))} \quad (9)$$

where $\text{Card}(R_*(Z))$ and $\text{Card}(R^*(Z))$ are the cardinalities of $R_*(Z)$ and $R^*(Z)$.

30.3 Identification of Upper and Lower Possibility Distributions

The upper and lower approximations of Z can be regarded as the optimal solutions of the following optimization problem.

$$\begin{aligned} \max_{R_l(Z), R_u(Z)} \quad & a(Z) = \frac{\text{Card}(R_l(Z))}{\text{Card}(R_u(Z))} \\ \text{s. t.} \quad & R_l(Z) \subseteq Z \subseteq R_u(Z), \end{aligned} \quad (10)$$

where $R_l(Z)$ and $R_u(Z)$ are definable sets by U/R . Similarly the model to identify the upper and lower possibility distributions can be formulated to maximize the fitness measure as follows:

$$\begin{aligned} \max_{\mathbf{a}, \mathbf{D}_l, \mathbf{D}_u} \quad & \beta = \sqrt[m]{\prod_{i=1}^m \frac{\pi_l(\mathbf{x}_i)}{\pi_u(\mathbf{x}_i)}} \\ \text{s. t.} \quad & \pi_l(\mathbf{x}_i) \leq h_i, \\ & \pi_u(\mathbf{x}_i) \geq h_i \\ & \pi_u(\mathbf{x}) \geq \pi_l(\mathbf{x}) \end{aligned} \quad (11)$$

The corresponding relations between dual approximations and dual possibility distributions are listed in Table 1.

Table 1. The similarities between rough set and possibility distributions

Possibility distributions	Rough sets
Upper distribution: $\pi_u(\mathbf{x})$	Upper approximation: $R^*(Z)$
Lower distribution: $\pi_l(\mathbf{x})$	Lower approximation: $R_*(Z)$
Product of $\pi_u(\mathbf{x}_i)$: $\prod_{i=1}^m \pi_u(\mathbf{x}_i)$	Cardinality of $R^*(Z)$: $Card(R^*(Z))$
Product of $\pi_l(\mathbf{x}_i)$: $\prod_{i=1}^m \pi_l(\mathbf{x}_i)$	Cardinality of $R_*(Z)$: $Card(R_*(Z))$
Inequality relation: $\pi_u(\mathbf{x}) \geq \pi_l(\mathbf{x})$	Inclusion relation: $R^*(Z) \supseteq R_*(Z)$
Measure of fitness: $\beta = \sqrt[m]{\prod_{i=1}^m \frac{\pi_l(\mathbf{x}_i)}{\pi_u(\mathbf{x}_i)}}$	Accuracy measure of a set Z : $\alpha(Z) = \frac{Card(R_*(Z))}{Card(R^*(Z))}$

It is straightforward that the objective function and constraints of (11) correspond to the objective function and constraints of (10), respectively. With considering that maximizing $\sqrt[m]{\prod_{i=1}^m \frac{\pi_l(\mathbf{x}_i)}{\pi_u(\mathbf{x}_i)}}$ is equivalent to maximizing

$\ln \sqrt[m]{\prod_{i=1}^m \frac{\pi_l(\mathbf{x}_i)}{\pi_u(\mathbf{x}_i)}} = (\sum_{i=1}^m (\ln \pi_l(\mathbf{x}_i) - \ln \pi_u(\mathbf{x}_i))) / m$, the optimization problem (11) can be rewritten as follows:

$$\begin{aligned}
 & \min_{\mathbf{a}, \mathbf{D}_u, \mathbf{D}_l} \sum_{i=1}^m (\mathbf{x}_i - \mathbf{a})' \mathbf{D}_l^{-1} (\mathbf{x}_i - \mathbf{a}) - \sum_{i=1}^m (\mathbf{x}_i - \mathbf{a})' \mathbf{D}_u^{-1} (\mathbf{x}_i - \mathbf{a}) & (12) \\
 & \text{s. t.} \quad (\mathbf{x}_i - \mathbf{a})' \mathbf{D}_l^{-1} (\mathbf{x}_i - \mathbf{a}) \geq -\ln h_i, \quad i=1, \dots, m, \\
 & \quad (\mathbf{x}_i - \mathbf{a})' \mathbf{D}_u^{-1} (\mathbf{x}_i - \mathbf{a}) \leq -\ln h_i, \quad i=1, \dots, m, \\
 & \quad \mathbf{D}_u - \mathbf{D}_l \geq 0, \\
 & \quad \mathbf{D}_l > 0.
 \end{aligned}$$

It should be noted that the optimization problem (12) is equivalent to the integrated model proposed in the paper [3,4] in form. However, they arise from very different consideration. The latter was used to integrate two optimization problems to obtain upper and lower possibility distributions simultaneously. The former is used to seek an optimal center vector \mathbf{a} and positive definite matrices \mathbf{D}_u and \mathbf{D}_l to maximize fitness measure β defined in formula (4). Model (11) makes it quite clear that upper and lower possibility distributions have very similar structure to the upper and lower approximations in rough sets theory. In the following, let us consider how to obtain center vector \mathbf{a} and positive matrices \mathbf{D}_l and \mathbf{D}_u .

Center vector \mathbf{a} can be approximately estimated as

$$\mathbf{a} = \mathbf{x}_{i^*}, \tag{13}$$

where \mathbf{x}_{i^*} denotes the vector whose grade is $h_{i^*} = \max_{k=1, \dots, m} h_k$. The associated possibility grade of \mathbf{x}_{i^*} is revised to be 1 because it becomes the center vector. Taking the transformation $\mathbf{y} = \mathbf{x} - \mathbf{a}$, the problem (12) is changed into the following problem.

$$\begin{aligned} \min_{\mathbf{D}_u, \mathbf{D}_l} \quad & \sum_{i=1}^m \mathbf{y}_i^t \mathbf{D}_l^{-1} \mathbf{y}_i - \sum_{i=1}^m \mathbf{y}_i^t \mathbf{D}_u^{-1} \mathbf{y}_i \\ \text{s. t.} \quad & \mathbf{y}_i^t \mathbf{D}_l^{-1} \mathbf{y}_i \geq -\ln h_i, \quad i=1, \dots, m, \\ & \mathbf{y}_i^t \mathbf{D}_u^{-1} \mathbf{y}_i \leq -\ln h_i, \quad i=1, \dots, m, \\ & \mathbf{D}_u - \mathbf{D}_l \geq 0, \\ & \mathbf{D}_l > 0 \end{aligned} \tag{14}$$

The formula (14) is a nonlinear optimization problem due to the last two constraints. To cope with this difficulty, we use principle component analysis (PCA) to rotate the given data (\mathbf{y}_i, h_i) to obtain a positive definite matrix easily. The data $\mathbf{y}_i (i=1, \dots, m)$ can be transformed by a linear transformation matrix \mathbf{T} whose columns are eigenvectors of the matrix $\Sigma = [\sigma_{ij}]$, where σ_{ij} is defined as

$$\sigma_{ij} = \left\{ \sum_{k=1}^m (x_{ki} - a_i)(x_{kj} - a_j)h_k \right\} / \sum_{k=1}^m h_k \tag{15}$$

Using the linear transformation matrix \mathbf{T} , the data \mathbf{y}_i is transformed into $\{\mathbf{z}_i = \mathbf{T}^t \mathbf{y}_i\}$. Then formulas (1) and (2) can be rewritten as follows:

$$\pi_l(\mathbf{z}_i) = \exp\{-\mathbf{z}_i^t \mathbf{T}^t \mathbf{D}_u^{-1} \mathbf{T} \mathbf{z}_i\}, \quad i=1, \dots, m, \tag{16}$$

$$\pi_u(\mathbf{z}_i) = \exp\{-\mathbf{z}_i^t \mathbf{T}^t \mathbf{D}_l^{-1} \mathbf{T} \mathbf{z}_i\}, \quad i=1, \dots, m. \tag{17}$$

Since \mathbf{T} is obtained by PCA, $\mathbf{T}^t \mathbf{D}_u^{-1} \mathbf{T}$ and $\mathbf{T}^t \mathbf{D}_l^{-1} \mathbf{T}$ can be assumed to be diagonal matrices as follows:

$$\mathbf{C}_u = \mathbf{T}^t \mathbf{D}_u^{-1} \mathbf{T} = \begin{pmatrix} c_{u1} & & & 0 \\ & \cdot & & \\ & & \cdot & \\ 0 & & & c_{um} \end{pmatrix}, \tag{18}$$

$$\mathbf{C}_l = \mathbf{T}' \mathbf{D}_l^{-1} \mathbf{T} = \begin{pmatrix} c_{l1} & & 0 \\ & \cdot & \\ 0 & & c_{ln} \end{pmatrix}. \quad (19)$$

Model (14) can be rewritten as the following LP problem:

$$\min_{\mathbf{C}_l, \mathbf{C}_u} \sum_{i=1}^m \mathbf{z}_i' \mathbf{C}_l \mathbf{z}_i - \sum_{i=1}^m \mathbf{z}_i' \mathbf{C}_u \mathbf{z}_i \quad (20)$$

$$\begin{aligned} \text{s. t. } & \mathbf{z}_i' \mathbf{C}_u \mathbf{z}_i \leq -\ln h_i, \quad i=1, \dots, m \\ & \mathbf{z}_i' \mathbf{C}_l \mathbf{z}_i \geq -\ln h_i, \quad i=1, \dots, m, \\ & c_{lj} \geq c_{uj}, \quad j=1, \dots, n, \\ & c_{uj} \geq \varepsilon, \quad j=1, \dots, n, \end{aligned}$$

where the condition $c_{lj} \geq c_{uj} \geq \varepsilon > 0$ makes the matrix $\mathbf{D}_u - \mathbf{D}_l$ semi-positive definite and matrices \mathbf{D}_u and \mathbf{D}_l positive. Denote the optimal solutions of (20) as \mathbf{C}_u^* and \mathbf{C}_l^* . Thus, we have

$$\begin{aligned} \mathbf{D}_u^* &= \mathbf{T} \mathbf{C}_u^{*-1} \mathbf{T}', \\ \mathbf{D}_l^* &= \mathbf{T} \mathbf{C}_l^{*-1} \mathbf{T}'. \end{aligned} \quad (21)$$

30.4 Conclusions

In this paper, from upper and lower directions the upper and lower possibility distributions are identified to approximate the given possibility grades, which is regarded as the expert's knowledge. The upper possibility distribution reflects the optimistic viewpoint of the expert and the lower possibility distribution reflects pessimistic one. The similarities between dual possibility distributions and upper and lower approximations in rough sets theory are investigated. It is obvious that they have homogenous structures.

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31. On Fractals in Information Systems: The First Step

Lech Polkowski^{1,2}

¹ Polish–Japanese Institute of Information Technology
Koszykowa 86, 02-008 Warsaw, Poland

² Department of Mathematics and Information Sciences
Warsaw University of Technology
Pl. Politechniki 1, 00-650 Warsaw, Poland
polkow@pjwstk.waw.pl

We introduce the notion of a fractal in an information system and we define a dimension function of a fractal in an information system parallel to the Minkowski dimension in Euclidean spaces. We prove basic properties of this new dimension.

31.1 Introduction

Objects called now "fractals" have been investigated since 1920's (cf. [31.3], [31.6]) yet the renewed interest in them goes back to 1970's in connection with studies of chaotic behavior, irregular non-smooth sets, dynamic systems, information compression and computer graphics (cf. [31.9]). The basic characteristics of "fractals" are rooted in dimension theory. The topological dimension theory assigns to any subset T of a (sufficiently regular) topological space X an integer $\dim T \geq -1$ called the *dimension* of T (cf. [31.7]). This dimension function, however, does not capture peculiar features of fractals among them the periodicity of local structure and appearance of details at any scale; for this reason, fractals are evaluated by means of other functions e.g. *Hausdorff dimension* or *Minkowski (box) dimension* better suited at capturing the peculiarities of local structure.

Many fractal objects can be generated by means of iterations of affine mappings (iterated function systems (cf. [31.8]) hence they allow for knowledge compression algorithms (cf. [31.1]; cf. also [31.11] for a rough set counterpart of the fractal collage theorem).

We are interested here in transferring the notion of a fractal to the general framework of rough set theory and we examine here some propositions for a counterpart of fractal dimension in this general framework.

31.2 Fractal Dimensions

For a set (for properties of fractal dimensions see [31.4], [31.5]) $T \subseteq E^n$, and $s \geq 0, \delta > 0$, one lets $H_\delta^s(T) = \inf \sum_i \text{diam}^s(Q_i)$, the infimum taken

over all families $\{Q_i : i = 1, 2, \dots\}$ of sets in E^n such that (i) $T \subseteq \bigcup_i Q_i$ (ii) $\text{diam}(Q_i) \leq \delta$. Then the limit $H^s(T) = \lim_{\delta \rightarrow 0^+} H_\delta^s(T)$ exists and it follows easily that there exists a unique s^* with the property that $H^s(T) = \infty$ for $s < s^*$ and $H^s(T) = 0$ for $s > s^*$. The real number s^* is the *Hausdorff dimension* of the set T , denoted $\text{dim}_{\mathcal{H}}(T)$. The Hausdorff dimension is too closely related to the metric structure of the underlying space to admit any substantial abstraction. For our purposes, the other function, the *Minkowski dimension* seems to be better suited. This dimension has an information theoretic content and may be transferred—with changes relaxing its geometric content—into a universe of a general information system.

For a bounded set $T \subseteq E^n$ (i.e. $\text{diam}(T) < \infty$), and $\delta > 0$, we denote by $n_\delta(T)$ the least number of n -cubes of diameter less than δ that cover T . Then we may consider the fraction $\frac{\log n_\delta(T)}{-\log \delta}$ and evaluate its limit. When the limit $\lim_{\delta \rightarrow 0^+} \frac{\log n_\delta(T)}{-\log \delta}$ exists, it is called the *Minkowski dimension* of the set T and it is denoted $\text{dim}_{\mathcal{M}}(T)$. One may interpret this dimension as an *information content* (cf. [31.2]) of T : the shortest description of T over an alphabet of δ -cubes has length of order of $\text{dim}_{\mathcal{M}}(T)$.

Both dimensions agree on "standard" fractal objects like the Cantor set (cf. [31.4], [31.5]) in general they disagree.

An advantage of the Minkowski dimension is that families of δ -cubes in its dimension may be selected in many ways, one among them is to consider a δ -grid of cubes of side length δ on E^n and to count the number $N_\delta(T)$ of those among them which intersect T ; then (cf. [31.4], [31.5]) if $\lim_{\delta \rightarrow 0^+} \frac{\log N_\delta(T)}{-\log \delta}$ exists it is equal to $\text{dim}_{\mathcal{M}}(T)$.

31.3 Rough Sets and Topologies on Rough Sets

Rough sets arise in an attempt at formalization of the notion of uncertain knowledge (cf. [31.10], [31.13]). In this paradigm, knowledge base is an *information system* $\mathcal{A} = (U, A)$ where U is the set of objects described by means of *attributes (features, properties)* collected in the set A . For an object $x \in U$ and an attribute $a \in A$ we denote by the symbol $a(x)$ the *value* of a on x . We admit here the case when the set U is infinite (e.g. E^n) and the set A consists of countably many attributes a_n where $n = 1, 2, \dots$. Each attribute a_n induces on U the $\{a_n\}$ -indiscernibility relation Ind_{a_n} viz. $x \text{Ind}_{a_n} y \Leftrightarrow a_n(x) = a_n(y)$ which partitions U into classes $[x]_{a_n}$; \mathcal{P}_n is the resulting partition. We may assume that $\mathcal{P}_{n+1} \subseteq \mathcal{P}_n$ for each n . A subset (*concept*) $Z \subseteq U$ is *n-exact* in case it is a union of a family of classes of Ind_{a_n} i.e. $Z = \bigcup \{[z]_{a_n} : z \in Z\}$. Otherwise, Z is said to be *n-rough*. Rough sets are approximated by exact sets: $Z_-^n = \bigcup \{[x]_{a_n} : [x]_{a_n} \subseteq Z\}$ and $Z_+^n = \bigcup \{[x]_{a_n} : [x]_{a_n} \cap Z \neq \emptyset\}$. The set Z_-^n is the *lower a_n -approximation* of Z and the set Z_+^n is the *upper a_n -approximation* of Z . A topological interpretation of Z_-^n, Z_+^n as *interior Int*, resp. *closure Cl* of Z in topology \mathcal{P}_n induced by the partition \mathcal{P}_n suggests (cf.

[31.12]) a topology $\Pi_{\mathcal{A}}$ on the set U by taking as an open base for this topology the family $\mathcal{P} = \bigcup_n \mathcal{P}_n$. A set Z is $\Pi_{\mathcal{A}}$ -exact in case $Int_{\Pi_{\mathcal{A}}} Z = Cl_{\Pi_{\mathcal{A}}} Z$ otherwise it is $\Pi_{\mathcal{A}}$ -rough. In this way, we define a taxonomy of sets in U : they may be divided into three classes: sets which are Π_n -exact, sets which are $\Pi_{\mathcal{A}}$ -exact and sets which are $\Pi_{\mathcal{A}}$ -rough (for a detailed study of topologies on rough sets see [31.12]).

We now consider an information system \mathcal{A}_C on the Euclidean space E^n ; this system consists of the universe $U = E^n$ and of attributes a_k for $k = 1, 2, \dots$ defined via partitions \mathcal{P}_k induced by relations Ind_{a_k} . The partition \mathcal{P}_k consists of n -cubes of the form

$$(c) \prod_{i=1}^n [m_i + \frac{j_i}{2^k}, m_i + \frac{j_i + 1}{2^k})$$

where m_i is an integer for each $i = 1, 2, \dots, n$ and $0 \leq j_i \leq 2^k - 1$ is an integer. From the definition of the Minkowski dimension we have

Proposition 1 If the Minkowski dimension $dim_{\mathcal{M}}(T)$ exists then $dim_{\mathcal{M}}(T) = \lim_{k \rightarrow \infty} \frac{\log N'_k}{k \log 2}$ where N'_k is the number of cubes in \mathcal{P}_k which do intersect T .

Proposition 2 For any $\Pi_{\mathcal{A}}$ -exact set Z , we have $dim_{\mathcal{M}}(Z) = n$.

Proof. Indeed, if a set Z is $\Pi_{\mathcal{M}}$ -exact then Z is a union of a family $\{Q_j : j = 1, 2, \dots\}$ of n -cubes of the form (c) and thus $n \geq dim_{\mathcal{M}}(T) \geq dim_{\mathcal{M}}(Q_1) = n$ by the monotonicity and stability of $dim_{\mathcal{M}}$ (cf. [31.5] Sect. 3.2 and Thm.3.4).

Corollary 1 Any set Z of fractional dimension $dim_{\mathcal{M}}$ is a $\Pi_{\mathcal{A}}$ -rough set.

The last fact directs us towards general information systems and rough sets resulting in them.

31.4 Fractals in Information Systems

For an information system $\mathcal{A} = (U, A)$ with the countable set $A = \{a_n : n = 1, 2, \dots\}$ of attributes such that $Ind_{a_{n+1}} \subseteq Ind_{a_n}$ for $n = 1, 2, \dots$, we will define the notion of an \mathcal{A} -dimension, denoted $dim_{\mathcal{A}}$. We will observe the information-theoretic content of the Minkowski dimension and thus—refraining from any geometric content, we introduce a normalization condition

$$(N) \ dim_{\mathcal{A}}(Q) = 1$$

for every equivalence class Q of any relation Ind_{a_n} . The condition (N) assures us that any equivalence class carries with itself a single bit of information, thus playing a role of an alphabet symbol.

We restrict ourselves to *bounded* subsets $Z \subseteq U$ i.e. such Z which for each n are covered by a finite number of equivalence classes of Ind_{a_n} . We may therefore assume that (i) the number of equivalence classes of Ind_{a_1} is k_1 (ii) each class of Ind_{a_n} ramifies into k_{n+1} classes of $Ind_{a_{n+1}}$.

We will say that the information system \mathcal{A} is of type $\kappa = (k_i)_i$.

For a bounded set $Z \subseteq U$, we let $dim_{\mathcal{A}}(Z) = \lim_{n \rightarrow \infty} \frac{\log \prod_{i=1}^n l_i}{\log \prod_{i=1}^n k_i}$ where l_i is the number of classes of Ind_{a_i} that intersect Z i.e. the number of classes in the upper approximation Z_i^+ of Z . Then we have

Proposition 3 In case \mathcal{A} is of type κ with $k_j \geq 2$ for infinitely many j , $dim_{\mathcal{A}}$ does satisfy (N).

Proof. Consider Q , a basic open set so that $Q = [x]_{a_k}$. We have

$$\lim_{n \rightarrow \infty} \frac{\log \prod_{i=1}^n l_i}{\log \prod_{i=1}^n k_i} = \lim_{n \rightarrow \infty} \frac{\log \prod_{i=k+1}^n k_i}{\log \prod_{i=1}^n k_i} = 1 - \lim_{n \rightarrow \infty} \frac{\log \prod_{i=1}^k k_i}{\log \prod_{i=1}^n k_i} = 1$$

where l_i is the number of Ind_{a_i} classes that intersect Q . Thus $dim_{\mathcal{A}}(Q) = 1$.

Let us observe that – as with the Minkowski dimension– the \mathcal{A} – dimension may be ramified into two weaker notions viz. the *upper* \mathcal{A} – dimension $\overline{dim}_{\mathcal{A}} = \limsup_{n \rightarrow \infty} \frac{\log \prod_{i=1}^n l_i}{\log \prod_{i=1}^n k_i}$ and the *lower* \mathcal{A} –dimension $\underline{dim}_{\mathcal{A}} = \liminf_{n \rightarrow \infty} \frac{\log \prod_{i=1}^n l_i}{\log \prod_{i=1}^n k_i}$.

Basic properties of $dim_{\mathcal{A}}$ parallel the respective properties of the Minkowski dimension.

Proposition 4 $dim_{\mathcal{A}}$ satisfies the following

1. $dim_{\mathcal{A}}(Z) \leq dim_{\mathcal{A}}(T)$ whenever $Z \subseteq T$
2. $\overline{dim}_{\mathcal{A}}(Z \cup T) = \max\{\overline{dim}_{\mathcal{A}}(Z), \overline{dim}_{\mathcal{A}}(T)\}$ in case \mathcal{A} is of type κ with $k_i \geq 2$ for infinitely many i
3. $dim_{\mathcal{A}}(Z) = dim_{\mathcal{A}}(Cl_{\Pi_{\mathcal{A}}} Z)$

Proof. Indeed, (i) follows by the very definition of $dim_{\mathcal{A}}$. For (ii), by (i) it follows that $\overline{dim}_{\mathcal{A}}(Z \cup T) \geq \max\{\overline{dim}_{\mathcal{A}}(Z), \overline{dim}_{\mathcal{A}}(T)\}$. To prove the converse let us assume that $\overline{dim}_{\mathcal{A}}(Z) \geq \overline{dim}_{\mathcal{A}}(T)$ and split infinite sequences of natural numbers into two classes (p_j denotes the number of classes of Ind_{a_j} intersecting Z and q_j means the same for T): (I) a sequence $(n_j)_j$ falls here in case $p_{n_j} < q_{n_j}$ for infinitely many j and $p_{n_j} \geq q_{n_j}$ for infinitely many j (II) a sequence falls here in case $p_{n_j} < q_{n_j}$ for almost every j (III) a sequence falls here in case $p_{n_j} \geq q_{n_j}$ for almost every j .

We assume that l_j is the number of classes of Ind_{a_j} intersecting $Z \cup T$; clearly $l_j \leq p_j + q_j$ for each j . Now consider a sub–sequence n_j for which $\frac{\log \prod_{i=1}^{n_j} l_i}{\log \prod_{i=1}^{n_j} k_i}$ converges. In case it falls into (II), we have $l_{n_j} \leq 2q_{n_j}$ for almost every j and thus $\lim_{j \rightarrow \infty} \frac{\log \prod_{i=1}^{n_j} l_i}{\log \prod_{i=1}^{n_j} k_i} \leq \lim_{j \rightarrow \infty} \frac{\log \prod_{i=1}^{n_j} 2q_i}{\log \prod_{i=1}^{n_j} k_i} \leq \overline{dim}_{\mathcal{A}}(T) \leq \overline{dim}_{\mathcal{A}}(Z)$.

Similarly in case the sequence falls into (III), $l_{n_j} \leq 2p_{n_j}$ for almost every j and thus $\lim_{j \rightarrow \infty} \frac{\log \prod_{i=1}^{n_j} l_i}{\log \prod_{i=1}^{n_j} k_i} \leq \overline{\dim}_{\mathcal{A}}(Z)$.

In case the sequence is in (I), by its convergence we have $\lim_{j \rightarrow \infty} \frac{\log \prod_{i=1}^{n_j} l_i}{\log \prod_{i=1}^{n_j} k_i} \leq \lim_{u \rightarrow \infty} \frac{\log \prod_{i=1}^u 2p_i}{\log \prod_{i=1}^u k_i}, \lim_{v \rightarrow \infty} \frac{\log \prod_{i=1}^v 2q_i}{\log \prod_{i=1}^v k_i} \leq \max\{\overline{\dim}_{\mathcal{A}}(Z), \overline{\dim}_{\mathcal{A}}(T)\} = \overline{\dim}_{\mathcal{A}}(Z)$ where u, v run respectively over indices n_j where $p_{n_j} < q_{n_j}, p_{n_j} \geq q_{n_j}$.

Finally, (iii) follows from the fact that $Q \cap Cl_{\Pi_{\mathcal{A}}} Z \neq \emptyset$ if and only if $Q \cap Z \neq \emptyset$ for every Q , a class of Ind_{a_n} , any n .

31.5 Conclusions

We have examined the notion of a fractal in the universe of an information system, and we have defined the \mathcal{A} -dimension proving its basic properties.

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32. Generalizations of Fuzzy Multisets for Including Infiniteness

Sadaaki Miyamoto

Institute of Engineering Mechanics and Systems
University of Tsukuba, Ibaraki 305-8573, Japan
miyamoto@esys.tsukuba.ac.jp

This paper aims at discussing two generalizations of fuzzy multisets in order to take infinite features into account. First, a class of fuzzy multisets having an infinite membership set for an element of the universe and finite cardinality is introduced. The sum, union, intersection as well as most t -norm and conorm operations except the drastic sum keep the property of the finite cardinality of the derived set. Second, the membership sequence is generalized to a closed set on the plane whereby both the fuzzy multiset and another fuzzification of multisets using the fuzzy number are discussed within this framework.

32.1 Introduction

Multisets, sometimes called bags, have been considered by many authors (e.g., [32.3, 32.1]) and used in a number of applications. Fuzzy multisets have also been considered by several researchers [32.6, 32.4]. An application of fuzzy multisets is information retrieval on Web, since an information item may appear more than once with possibly different degrees of relevance to a query [32.5].

This application invokes interesting problems. Huge amount, almost infinite, of information items exists in the space of WWW. A query may search a very large number of the items wherefrom all information is unable to be obtained by human capability. We thus observe a small part of the obtained information pieces. Such experiences lead us to consideration of infinite fuzzy multisets. The infiniteness implies that although the information pieces may be finite but the number of information items is very large and there is no fixed upper bound to this number.

We are concerned with infinite fuzzy multisets in this paper. The infiniteness does not mean the universal space on which fuzzy multisets are discussed is infinite. It means that a membership set for an element the universe is infinite even when the underlying crisp multisets cannot have infinite multiplicity. We introduce a class of infinite fuzzy multisets for which the cardinality is finite, and shows that most t -norm and conorm operations for two sets in this class keep the derived set within this class.

Second generalization of fuzzy multisets is moreover considered. There is another fuzzification of a multiset using the fuzzy number. This generalization essentially include the both fuzzifications using the membership sets and the fuzzy number in a unified framework.

32.2 Multisets and Fuzzy Multisets

A multiset M of X is characterized by the count function $C_M: X \rightarrow \{0, 1, 2, \dots\}$. Thus, $C_M(x)$ is the number of copies of the element $x \in X$.

The followings are basic relations and operations for crisp multisets;

(inclusion): $M \subseteq N \Leftrightarrow C_M(x) \leq C_N(x), \forall x \in X$.

(equality): $M = N \Leftrightarrow C_M(x) = C_N(x), \forall x \in X$.

(union): $C_{M \cup N}(x) = C_M(x) \vee C_N(x)$.

(intersection): $C_{M \cap N}(x) = C_M(x) \wedge C_N(x)$.

(sum): $C_{M+N}(x) = C_M(x) + C_N(x)$.

It is reasonable to assume that the number $C_M(\cdot)$ should be finite. Moreover we assume X is finite: $X = \{x_1, \dots, x_n\}$.

A *fuzzification* of the multiset is to define $C_M(x)$ in terms of fuzzy numbers. We thus use the above definitions but $C_M(x)$ and $C_N(x)$ are assumed to be *nonnegative fuzzy numbers*.

A *fuzzy multiset* A of X (more often called fuzzy bag) is characterized by the function $C_A(\cdot)$ of the same symbol, but the value $C_A(x)$ is a finite set in I [32.6]. Given $x \in X$, $C_A(x) = \{\mu, \mu', \dots, \mu''\}$, $\mu, \mu', \dots, \mu'' \in I$.

For two fuzzy multisets A and B of X such that $C_A(x) = \{\mu, \mu', \dots, \mu''\}$, $C_B(x) = \{\nu, \nu', \dots, \nu'''\}$, the sum $A + B$ is $C_{A+B}(x) = \{\mu, \mu', \dots, \mu'', \nu, \nu', \dots, \nu'''\}$, but other operations need another representation called membership sequence [32.4].

A membership sequence is defined for each $C_A(x) = \{\mu, \mu', \dots, \mu''\}$; the set $\{\mu, \mu', \dots, \mu''\}$ is arranged into the decreasing order denoted by $\mu_A^1(x), \mu_A^2(x), \dots, \mu_A^m(x)$: $\{\mu_A^1(x), \mu_A^2(x), \dots, \mu_A^m(x)\} = \{\mu, \mu', \dots, \mu''\}$ ($\mu_A^1(x) \geq \mu_A^2(x) \geq \dots \geq \mu_A^m(x)$). The followings are other basic relations and operations for fuzzy multisets [32.4]; they are given in terms of the membership sequences.

1. **inclusion:** $A \subseteq B \Leftrightarrow \mu_A^j(x) \leq \mu_B^j(x), j = 1, \dots, m, \forall x \in X$.
2. **equality:** $A = B \Leftrightarrow \mu_A^j(x) = \mu_B^j(x), j = 1, \dots, m, \forall x \in X$.
3. **union:** $\mu_{A \cup B}^j(x) = \mu_A^j(x) \vee \mu_B^j(x), j = 1, \dots, m, \forall x \in X$.
4. **intersection:** $\mu_{A \cap B}^j(x) = \mu_A^j(x) \wedge \mu_B^j(x), j = 1, \dots, m, \forall x \in X$.
5. **t -norm and conorm:**

$$\mu_{A \text{TB}}^j(x) = t(\mu_A^j(x), \mu_B^j(x)), j = 1, \dots, m, \forall x \in X.$$

$$\mu_{A \text{SB}}^j(x) = s(\mu_A^j(x), \mu_B^j(x)), j = 1, \dots, m, \forall x \in X.$$

Remark that there are different types of t -norms and conorms: we consider the algebraic product and sum, the bounded product and sum, the Frank family, the Hamacher family, the Yager family, the Sugeno family, and lastly the drastic product and sum [32.2]. All t -norms and conorms are denoted by single letters **T** and **S** except the last one; the drastic product and sum are denoted by **T_D** and **S_D**, respectively.

32.3 Infinite Memberships

Even when crisp multisets cannot admit infinite values of the function $C_M(x)$, fuzzy multisets are capable of having infinite number of memberships. Remark that every infinite set does not provide a well-defined fuzzy multiset, since an α -cut of a fuzzy multiset should give a crisp multiset of the finite count.

Instead of the finite set, infinite $C_A(x) = \{\mu, \mu', \dots\}$ is used. We assume that the members $\{\mu, \mu', \dots\}$ of $C_A(x)$ can be arranged into the decreasing order:

$$C_A(x) = \{\mu_A^1(x), \mu_A^2(x), \dots\}, \quad \mu_A^1(x) \geq \mu_A^2(x) \geq \dots$$

In order that the α -cuts provide well-defined crisp multisets, it is necessary and sufficient that $\mu_A^j(x) \rightarrow 0$, as $j \rightarrow \infty$, for all $x \in X$. This class of fuzzy multiset of X is denoted by $\mathcal{FM}_0(X)$.

The operations such as $A + B$, $A \cup B$, *etc.* are defined in the same way as above except that $m \rightarrow \infty$ in the definitions. We have

Proposition 1. For $A, B \in \mathcal{FM}_0(X)$, $A + B \in \mathcal{FM}_0(X)$, $A \cup B \in \mathcal{FM}_0(X)$, $A \cap B \in \mathcal{FM}_0(X)$, $\mathbf{ATB} \in \mathcal{FM}_0(X)$, $\mathbf{ASB} \in \mathcal{FM}_0(X)$, except the drastic sum: $\mathbf{AS}_D B \in \mathcal{FM}_0(X)$ does not necessarily hold.

A basic measure of a fuzzy set F is its cardinality defined by $|F| = \sum_{x \in X} \mu_F(x)$. When a fuzzy multiset A of finite membership sets is considered, its generalization is immediate:

$$|A| = \sum_{x \in X} \sum_{j=1}^m \mu_A^j(x).$$

Let us consider the cardinality for the infinite memberships. We define

$$|A|_x = \sum_{j=1}^{\infty} \mu_A^j(x). \tag{32.1}$$

Then, $|A| = \sum_{x \in X} |A|_x$. It is easy to see that $|A|$ is finite if and only if $|A|_x$ is finite for all $x \in X$, since we are considering finite X .

Note that for some sets, say $B \in \mathcal{FM}_0(X)$, $|B|_x = +\infty$. (Consider $\mu_B^j(x) = 1/j$.) We hence introduce a subclass $\mathcal{FM}_1(X)$ for which the cardinality is finite:

$$\mathcal{FM}_1(X) = \{A \in \mathcal{FM}_0(X) : |A|_x < \infty, \forall x \in X\}. \tag{32.2}$$

We now have the following proposition.

Proposition 2. For arbitrary $A, B \in \mathcal{FM}_1(X)$, $A+B \in \mathcal{FM}_1(X)$, $A \cup B \in \mathcal{FM}_1(X)$, $A \cap B \in \mathcal{FM}_1(X)$, $ATB \in \mathcal{FM}_1(X)$, $ASB \in \mathcal{FM}_1(X)$, except the drastic sum: $AS_D B$ is not necessarily in $\mathcal{FM}_1(X)$.

It should be noted that most, but not all, t -conorms keep the derived sets within \mathcal{FM}_1 .

32.4 A Set-Valued Multiset

It seems that nothing is in common between fuzzy multisets and fuzzification by fuzzy numbers. On the contrary, there is a generalized framework in which the two kinds of *fuzzified* multisets are put.

Let us notice that the membership sequence, whether it is finite or infinite, is regarded as a nonincreasing step function. In view of this, we first consider a monotone nonincreasing function $\zeta_A(y; x)$ of the variable $y \in [0, +\infty)$ with the values in $[0, +\infty)$ for every $x \in X$ as a parameter. Moreover the function is assumed to satisfy $\zeta_A(y; x) \rightarrow 0$ as $y \rightarrow \infty$. Even if we do not assume any kind of continuity, it is well-known that the function $\zeta_A(y; x)$ is continuous almost everywhere due to the monotone property. We moreover assume, for the next step, that the function is upper-semicontinuous.

Second, this function $\zeta_A(y; x)$ is transformed to a closed set $\nu_A(y, z; x)$ on the (y, z) -plane; we use the set $\nu_A(\cdot, \cdot; x)$ as the membership for the generalized fuzzy multiset. This set is defined by

$$\nu_A(y, z; x) = \{(y, z) \in [0, \infty)^2 : \zeta_A(y; x) \geq z\}.$$

Another function $\eta_A(z; x)$ with the variable z derived from ν_A is moreover defined:

$$\eta_A(z; x) = \sup\{y \in \nu_A(y, z; x)\}, \quad (z \in (0, \infty)).$$

It is evident that if we define

$$\begin{aligned} \nu'_A(z, y; x) &= \{(y, z) \in [0, \infty) \times (0, \infty) : \eta_A(z; x) \geq y\} \\ &\cup \{(y, 0) : y \in [0, \infty)\}, \end{aligned} \tag{32.3}$$

then $\nu_A(y, z; x) = \nu'_A(z, y; x)$.

The generalized fuzzy multiset A is characterized by $\nu_A(y, z; x)$.

For two generalized fuzzy multisets A and B of X , the basic relations and operations are defined by the operations on the sets ν_A and ν_B .

- (I) (inclusion). $A \subseteq B \Leftrightarrow \nu_A(\cdot, \cdot; x) \subseteq \nu_B(\cdot, \cdot; x), \forall x \in X$.
- (II) (equality). $A = B \Leftrightarrow \nu_A(\cdot, \cdot; x) = \nu_B(\cdot, \cdot; x), \forall x \in X$.
- (III) (sum). Define $\eta_{A+B}(z; x) = \eta_A(z; x) + \eta_B(z; x)$ and derive ν'_{A+B} from $\eta_{A+B}(z; x)$ using (32.3).
Define ν_{A+B} by $\nu_{A+B}(y, z; x) = \nu'_{A+B}(z, y; x)$.
- (IV) (union). Define $\zeta_{A \cup B}(y; x) = \zeta_A(y; x) \vee \zeta_B(y; x)$ and derive $\nu_{A \cup B}$ from $\zeta_{A \cup B}(y; x)$.
- (V) (intersection). Define $\zeta_{A \cap B}(y; x) = \zeta_A(y; x) \wedge \zeta_B(y; x)$ and derive $\nu_{A \cap B}$ from $\zeta_{A \cap B}(y; x)$.
- (VI) (t -norm and conorm). Define $\zeta_{A \mathbf{T} B}(y; x) = t(\zeta_A(y; x), \zeta_B(y; x));$
 $\zeta_{A \mathbf{S} B}(y; x) = s(\zeta_A(y; x), \zeta_B(y; x))$ and derive $\nu_{A \mathbf{T} B}$ and $\nu_{A \mathbf{S} B}$ from $\zeta_{A \mathbf{T} B}(y; x)$ and $\zeta_{A \mathbf{S} B}(y; x)$, respectively.

It is evident that this generalization includes the fuzzy multisets and positive real-valued multisets [32.1], whereas it is not obvious that this also includes the fuzzification by the fuzzy number.

A simple mapping from the class of $C_A(x)$ as a fuzzy number to $\zeta_A(\cdot; x)$ is used for showing this generalization encompasses the fuzzification of multisets using fuzzy numbers. Notice that $C_A(x)$, a fuzzy number, consists of two upper-semicontinuous functions $L(y)$ and $R(y)$: $C_A(x) = L(y), (0 \leq y \leq c)$ and $C_A(x) = R(y), (c \leq y)$, where $L(c) = R(c) = 1$.

First, $L(y)$ is transformed into a lower-semicontinuous function $\tilde{L}(y)$ which is equal to $L(y)$ on all continuity points. Then $C_A(x)$ is mapped to $\zeta_A(\cdot; x)$ by the next rule:

$$\zeta_A(y; x) = \begin{cases} 1 - \frac{1}{2}\tilde{L}(y), & 0 \leq y \leq c, \\ \frac{1}{2}R(y), & c < y. \end{cases}$$

It is immediate to see that the inclusion and equality as well as the operations of the sum, union, and intersection for the fuzzification by the fuzzy number is expressed in terms of the present generalization by the above mapping.

32.5 Conclusion

We have discussed two generalizations which include infinite features in fuzzy multisets. In the first generalization a subclass of finite cardinality has been introduced and it has been shown that the standard set operations are performed within this class, whereas an exceptional t -conorm of the drastic sum may put the derived set out of this class. More general results will be expected about t -conorms.

In the second generalization two fuzzifications of the crisp multiset are considered in the unified framework. When compared with the first generalization, the latter is more general.

Multisets have close relationships with rough sets and their generalizations [32.7]. Theoretical aspects of fuzzy multisets in relation to rough sets should further be considered.

We have suggested application of infinite fuzzy multisets to information retrieval on WWW. More efforts should be concentrated on such applications as future studies.

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33. Fuzzy c -Means and Mixture Distribution Model for Clustering Based on L_1 -Space

Takatsugu Koga¹, Sadaaki Miyamoto², and Osamu Takata³

¹ Graduate School of Systems and Information Engineering
University of Tsukuba, Ibaraki 305-8573, Japan
koga@odin.esys.tsukuba.ac.jp

² Institute of Engineering Mechanics and Systems, University of Tsukuba

³ Doctoral Program in Engineering, University of Tsukuba

This paper aims at proposing and comparing two fuzzy models and a statistical model for clustering based on L_1 -space. Clustering methods in the fuzzy models are the standard fuzzy c -means and an entropy regularization method based on L_1 -space. Furthermore, we add new variables to them for improving the cluster division. In the statistical model, a mixture distribution model based on L_1 -space is proposed and the EM algorithm is applied.

33.1 Introduction

A characteristic of methods of data clustering is that various measures of distance and similarity between objects can be employed [33.1, 33.5]. For example, the L_1 space, instead of the most known Euclidean space, is sometimes useful in crisp and fuzzy c -means.

Several results have been published in fuzzy c -means based on the L_1 -space [33.3, 33.7, 33.9], and studies are ongoing in order to improve the method and to investigate the properties of the clusters theoretically. For example, the method of entropy regularization and fuzzy classification functions [33.9, 33.8] should be studied; additional variables for clustering can be taken into account [33.6].

The aim of the present paper is to include new variables into the methods of the standard fuzzy c -means [33.2] and the entropy fuzzy c -means [33.10] based on the L_1 -metric. In addition, a new mixture distribution model on the L_1 -space is proposed in which the EM algorithm [33.4, 33.11] is used to estimate parameters.

33.2 Fuzzy c -Means Based on L_1 -Space

Assume that the p -dimensional space \mathbf{R}^p is equipped with the weighted L_1 -norm: for $x = (x^1, \dots, x^p)$ and $y = (y^1, \dots, y^p)$ in \mathbf{R}^p ,

$$\|x - y\| = \sum_{j=1}^p w^j |x^j - y^j|,$$

where (w^1, \dots, w^p) is the weight vector. A set $X = \{x_1, \dots, x_n\}$ of objects $x_k = (x_k^1, \dots, x_k^p) \in \mathbf{R}^p$ should be divided into c clusters. Clusters are denoted by G_i ($i = 1, \dots, c$) or simply i . Center for cluster i is denoted by $v_i = (v_i^1, \dots, v_i^p)$; we write $V = (v_1, \dots, v_c)$ for simplicity. The membership matrix is $U = (u_{ik})$; u_{ik} is the degree of membership of x_k to cluster i .

The method of fuzzy c -means uses an alternative minimization of an objective function $J(U, V)$. In addition to U and V , we use more variables $\alpha = (\alpha_1, \dots, \alpha_c)$ for controlling the sizes of clusters and $\eta = (\eta_i^j)$ for controlling the scatters of them.

We consider the following two objective functions.

$$J_{std}(U, V, \alpha, \eta) = \sum_{i=1}^c \alpha_i \sum_{k=1}^n \left(\frac{u_{ik}}{\alpha_i} \right)^m \sum_{j=1}^p \eta_i^j |x_k^j - v_i^j|$$

$$J_{ent}(U, V, \alpha, \eta) = \sum_{i=1}^c \sum_{k=1}^n u_{ik} \sum_{j=1}^p \eta_i^j |x_k^j - v_i^j| + \lambda^{-1} \sum_{i=1}^c \sum_{k=1}^n u_{ik} \log \frac{u_{ik}}{\alpha_i}$$

The subscript *std* and *ent* imply that the methods are standard fuzzy c -means [33.2] and the method of entropy regularization [33.10, 33.8], respectively. Each function has its parameter: $m(> 1)$ in J_{std} and $\lambda(> 0)$ in J_{ent} .

The constraints for U , α , and η are

$$M = \left\{ (u_{ik}) \mid u_{ik} \in [0, 1], \sum_{i=1}^c u_{ik} = 1, k = 1, \dots, n \right\},$$

$$A = \left\{ (\alpha_i) \mid \alpha_i \in [0, 1], \sum_{i=1}^c \alpha_i = 1 \right\},$$

$$H = \left\{ (\eta_i^j) \mid \eta_i^j > 0, \prod_{j=1}^p \eta_i^j = 1, i = 1, \dots, c \right\}.$$

The next alternative optimization algorithm **FCM** is used for clustering in which $J = J_{ent}$ or $J = J_{std}$.

Algorithm FCM.

FCM1. Set initial values \bar{V} and $\bar{\alpha}$ $C\bar{\eta}$.

FCM2. Solve $\min_{U \in M} J(U, \bar{V}, \bar{\alpha}, \bar{\eta})$ and let the solution be \bar{U} .

FCM3. Solve $\min_V J(\bar{U}, V, \bar{\alpha}, \bar{\eta})$ and let the solution be \bar{V} .

FCM4. Solve $\min_{\alpha \in A} J(\bar{U}, \bar{V}, \alpha, \bar{\eta})$ and let the solution be $\bar{\alpha}$.

FCM5. Solve $\min_{\eta \in H} J(\bar{U}, \bar{V}, \bar{\alpha}, \eta)$ and let the solution be $\bar{\eta}$.

FCM6. If the solution $(\bar{U}, \bar{V}, \bar{\alpha}, \bar{\eta})$ is convergent, stop; otherwise go to **FCM2**.

The optimal solutions of U , α , and η for $J = J_{ent}$ and $J = J_{std}$ are as follows. For the cluster centers V , we do not have a closed formula. Instead, an efficient algorithm can be employed. For simplicity we put $D_{ik} = \sum_{j=1}^p \eta_i^j |x_k^j - v_i^j|$.

(i) $J = J_{std}$:

$$u_{ik} = \left[\sum_{\ell=1}^c \frac{\alpha_{\ell}}{\alpha_i} \left(\frac{D_{i\ell k}}{D_{\ell k}} \right)^{\frac{1}{m-1}} \right]^{-1}, \quad \alpha_i = \left[\sum_{\ell=1}^c \left(\frac{\sum_{k=1}^n (u_{\ell k})^m D_{\ell k}}{\sum_{k=1}^n (u_{ik})^m D_{ik}} \right)^{\frac{1}{m}} \right]^{-1},$$

$$\eta_i^j = \left[\prod_{\ell=1}^p \left(\frac{\sum_{k=1}^n (u_{ik})^m |x_k^j - v_i^j|}{\sum_{k=1}^n (u_{ik})^m |x_k^{\ell} - v_i^{\ell}|} \right)^{\frac{1}{p}} \right]^{-1}.$$

(ii) $J = J_{ent}$:

$$u_{ik} = \frac{\alpha_i e^{-\lambda D_{ik}}}{\sum_{\ell=1}^c \alpha_{\ell} e^{-\lambda D_{\ell k}}}, \quad \alpha_i = \frac{1}{n} \sum_{k=1}^n u_{ik}, \quad \eta_i^j = \left[\prod_{\ell=1}^p \left(\frac{\sum_{k=1}^n u_{ik} |x_k^j - v_i^j|}{\sum_{k=1}^n u_{ik} |x_k^{\ell} - v_i^{\ell}|} \right)^{\frac{1}{p}} \right]^{-1}.$$

Calculation of V (cf. [33.9]).

First, $x_1^j, x_2^j, \dots, x_{n-1}^j, x_n^j$ are sorted into the increasing order.

$$\begin{array}{c} x_1^j, x_2^j, \dots, x_{n-1}^j, x_n^j \\ \downarrow \text{SORT} \\ x_{q(1)}^j \leq x_{q(2)}^j \leq \dots \leq x_{q(n-1)}^j \leq x_{q(n)}^j \end{array}$$

Algorithm C:

```

begin
   $S := -\frac{1}{2} \sum_{k=1}^n (\bar{u}_{ik})^m;$ 
   $r := 0;$ 
  while ( $S < 0$ ) do begin
     $r := r + 1;$ 
     $S := S + (\bar{u}_{iq(r)})^m;$ 
  end;
  output  $\bar{v}_i^j = x_{q(r)}^j$ 
end.
```

This algorithm is for V in J_{std} ; For J_{ent} , $(\bar{u}_{ik})^m$ should be replaced by \bar{u}_{ik} . Notice that this algorithm is very fast, since the computation of $O(np)$ is sufficient in the main loop of iteration except the initial sorting.

33.3 Mixture Distribution Based on L_1 -Space

Mixture distribution model can be used for clustering [33.5, 33.11]. Our purpose is to develop a mixture distribution model for L_1 -space, in contrast to the Gaussian mixture model for the Euclidean space. Three elements are used in clustering by a mixture distribution.

- (i) the prior probability of occurrence of the cluster $G_i: P(G_i) = \alpha_i$,
- (ii) the conditional probability of x given $G_i: P(x|G_i) = \int_{-\infty}^x p_i(x|\phi_i)$,
- (iii) the probability $P(G_i|x)$ by which an observation x is allotted to G_i .

Notice the Bayes formula:

$$P(G_i|x) = \frac{P(G_i)P(x|G_i)}{\sum_{j=1}^c P(G_j)P(x|G_j)} = \frac{\alpha_i p_i(x|\phi_i)}{\sum_{j=1}^c \alpha_j p_j(x|\phi_j)}. \tag{33.1}$$

We must assume the density $p_i(x|\phi_i)$ and estimate the parameters α_i and ϕ_i ($i = 1, \dots, c$). Since the Gaussian distribution cannot be used in L_1 -space, we assume the following density function:

$$p_i(x|\phi_i) = p_i(x|\mu_i, \nu_i) = \prod_{j=1}^p \left\{ \frac{\nu_i^j}{2} e^{-\nu_i^j |x^j - \mu_i^j|} \right\}$$

where the parameter $\phi_i = (\mu_i^1, \dots, \mu_i^p, \nu_i^1, \dots, \nu_i^p)$ is $2p$ -dimensional vector.

In order to estimate the vector parameter $\Phi = (\alpha_1, \dots, \alpha_c, \phi_1, \dots, \phi_c)$, the EM algorithm [33.4, 33.11] is used. Let

$$Q(\Phi|\Phi^{(\ell)}) = \sum_{i=1}^c \Psi_i^{(\ell)} \log \alpha_i + \sum_{i=1}^c \sum_{k=1}^n \psi_{ik}^{(\ell)} \log p_i(x_k|\phi_i).$$

The EM algorithm.

- (O) Set initial value of $\Phi^{(0)}$ for the parameter Φ . Put $\ell = 0$.
Repeat (E) and (M) until convergence.
- (E) Calculate $Q(\Phi|\Phi^{(\ell)})$.
- (M) Solve $\max_{\Phi} Q(\Phi|\Phi^{(\ell)})$ and let the optimal solution be $\bar{\Phi}$.
Put $\ell = \ell + 1$ and $\Phi^{(\ell)} = \bar{\Phi}$.

End EM.

The solution in the step (M) is given as follows. Put

$$\psi_{ik}^{(\ell)} = \frac{\alpha_i^{(\ell)} p_i(x_k|\phi_i^{(\ell)})}{\sum_{j=1}^c \alpha_j^{(\ell)} p_j(x_k|\phi_j^{(\ell)})}, \quad w_{ik}^{(\ell)} = \frac{\psi_{ik}^{(\ell)}}{\sum_{k'=1}^n \psi_{ik'}^{(\ell)}}.$$

Optimal α_i : $\alpha_i = \frac{1}{n} \sum_{k=1}^n \psi_{ik}^{(\ell)}$ ($i = 1, \dots, c$).

Calculation of μ_i^j .

This algorithm is essentially the same as the former algorithm for calculating the cluster centers. First the sorting (33.2) is performed. The algorithm **C** in the previous section is then applied with the obvious replacement of $(\bar{u}_{ik})^m$ and $(\bar{u}_{iq(r)})^m$ into $w_{ik}^{(\ell)}$ and $w_{iq(r)}^{(\ell)}$, respectively.

Lastly, ν_i^j is obtained in terms of the optimal $\bar{\mu}_i^j$:

$$\nu_i^j = \frac{1}{\sum_{k=1}^n w_{ik}^{(\ell)} |x_k^j - \bar{\mu}_i^j|}.$$

33.4 Conclusion

L_1 -based methods of the standard and entropy fuzzy c -means with additional variables of the sizes and scatters of the clusters as well as the mixture distribution model have been proposed and algorithms have been developed. In the mixture distribution model, it has been shown that the EM algorithm is employed.

Future studies include application to real data, in particular data mining applications are promising, since binary and nominal data should be dealt with, which means that L_1 -space is a suitable framework.

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34. On Rough Sets under Generalized Equivalence Relations

Masahiro Inuiguchi and Tetsuzo Tanino

Department of Electronics and Information Systems
Graduate School of Engineering, Osaka University
2-1, Yamada-Oka, Suita, Osaka 565-0871, Japan
{inuiguti, tanino}@eie.eng.osaka-u.ac.jp
<http://vanilla.eie.eng.osaka-u.ac.jp>

We consider two generalized situations: a case when an equivalence relation is generalized to a similarity relation and a case when a partition is generalized to a cover. Two interpretations of rough sets, i.e., the approximation by means of elementary sets and the distinction among positive, negative and boundary regions, are conceivable. The relations between two generalized situations are investigated. Rough sets are generalized based on two different interpretations under two different situations. Fundamental properties and complete definability are discussed in each generalization.

34.1 Introduction

Rough sets were originally proposed in the presence of an equivalence relation. An equivalence relation is sometimes difficult to be obtained in realworld problems due to the vagueness and incompleteness of human knowledge. From this point of view, the concept of rough sets has been extended to cases when a similarity relation and a fuzzy partition are given (see [34.1]-[34.4]). However we have different definitions of rough sets even under the same generalized equivalence relation. Those different definitions coincide when the generalized equivalence relation degenerate to an equivalence relation. In spite of this difference, the reason has not discussed considerably, so far.

In this paper, we demonstrate that there are two interpretations of rough sets and two generalized problem settings. In crisp cases, one of the two generalized settings is a situation that a similarity relation instead of an equivalence relation is given and the other is a situation that a cover instead of the partition associated with an equivalence relation is given. Rough sets composed of lower and upper approximations are interpreted in two different ways: distinction among positive, negative and boundary elements of a given subset and approximation of a given subset by means of elementary sets obtained from a similarity relation or a cover. Restricting ourselves into crisp cases, we discuss the relations between two different settings, how definitions of rough sets are different depending on the interpretation, fundamental properties of rough sets under those interpretations and the complete definability of rough sets.

Table 34.1. Fundamental properties of rough sets

(i)	$R_*(X) \subseteq X \subseteq R^*(X)$
(ii)	$R_*(\emptyset) = R^*(\emptyset) = \emptyset, R_*(U) = R^*(U) = U$
(iii)	$R_*(X \cap Y) = R_*(X) \cap R_*(Y), R^*(X \cup Y) = R^*(X) \cup R^*(Y)$
(iv)	$X \subseteq Y$ implies $R_*(X) \subseteq R_*(Y), X \subseteq Y$ implies $R^*(X) \subseteq R^*(Y)$
(v)	$R_*(X \cup Y) \supseteq R_*(X) \cup R_*(Y), R^*(X \cap Y) \subseteq R^*(X) \cap R^*(Y)$
(vi)	$R_*(U - X) = U - R^*(X), R^*(U - X) = U - R_*(X)$
(vii)	$R_*(R_*(X)) = R^*(R_*(X)) = R_*(X), R^*(R^*(X)) = R_*(R^*(X)) = R^*(X)$

34.2 The Original Rough Sets

Let R be an equivalence relation in the finite universe U . In rough set literature, R is referred to as an indiscernibility relation and a pair (U, R) is called an approximation space. By the equivalence relation R, U can be partitioned into a collection of elementary sets, $U/R = \{E_1, E_2, \dots, E_n\}$. Define $R(x)$ as $R(x) = \{y \in U \mid yRx\}$. Then we have $x \in E_i$ if and only if $E_i = R(x)$.

In rough sets, we consider the approximations of an arbitrary set $X \subseteq U$ by means of elementary sets. Then the rough set of X is defined by a pair of the following lower and upper approximations:

$$R_*(X) = \{x \in U \mid R(x) \subseteq X\}, \quad R^*(X) = \{x \in U \mid R(x) \cap X \neq \emptyset\}. \tag{34.1}$$

By the definition, $R_*(X) \subseteq R^*(X)$ holds. If $R_*(X) = R^*(X)$ holds then X is said to be completely definable under the approximation space (X, U) .

Under indiscernible circumstances given by (U, A) , we cannot recognize the difference among elements in E_i but between $x \in E_i$ and $y \in E_j$ ($i \neq j$). Thus, what we can specify is not a particular element x of U but a particular elementary set E_i of U/R . Consider an element to which we know only it is in E_i . If $E_i \subseteq R_*(X)$, we can conclude that the element belongs to X . If $E_i \subseteq U - R^*(X)$, we can conclude that the element does not belong to X . From those facts, $R_*(X)$ and $U - R^*(X)$ are regarded as the positive and negative regions of X , respectively. $R^*(X) - R_*(X)$ is regarded as the ambiguous region.

The fundamental properties of $R_*(X)$ and $R^*(X)$ are listed in Table 34.1. Let

$$R_*^1(X) = \begin{cases} \bigcup_{R(x) \subseteq X} R(x), & \text{if } \exists R(x); R(x) \subseteq X, \\ \emptyset, & \text{otherwise,} \end{cases} \tag{34.2}$$

$$R_*^2(X) = \begin{cases} \bigcap_{R(x) \cap (U-X) \neq \emptyset} (U - R(x)), & \text{if } \exists R(x); R(x) \cap (U - X) \neq \emptyset, \\ U, & \text{otherwise,} \end{cases} \tag{34.3}$$

$$R_1^*(X) = \begin{cases} \bigcap_{R(x) \cap X = \emptyset} (U - R(x)), & \text{if } \exists R(x); R(x) \cap X = \emptyset, \\ U, & \text{otherwise,} \end{cases} \quad (34.4)$$

$$R_2^*(X) = \begin{cases} \bigcup_{R(x) \cap X \neq \emptyset} R(x), & \text{if } \exists R(x); R(x) \cap X \neq \emptyset, \\ \emptyset, & \text{otherwise.} \end{cases} \quad (34.5)$$

Since R is an equivalent relation, we have $R_*(X) = R_*^1(X) = R_*^2(X)$ and $R^*(X) = R_1^*(X) = R_2^*(X)$.

34.3 Two Different Problem Settings

An equivalence relation R is identified by a partition $U|R = \{E_1, E_2, \dots, E_n\}$ and vice versa. From this fact, there are two possible generalization schemes: generalization of R and generalization of $U|R$ (see [34.2]).

Generalization of R is to drop and/or to weaken some of the requirements of R so that R can be considered the so-called similarity relation, i.e., xRy means ‘ x is similar to y ’. Until now R is generalized up to a relation which satisfies only the reflexivity (see [34.4]). On the other hand, generalization of $U|R$ is to give a cover of U , i.e., a class $\mathcal{F} = \{F_1, F_2, \dots, F_n\}$ such that $U = \bigcup_{i=1}^n F_i$ (see [34.1]).

Let us discuss relations between those generalizations. First consider a case that a similarity relation R is given. When R is no longer symmetric, a set of elements similar to x , i.e., $R(x)$ is distinct from $R^{-1}(x) = \{y \mid xRy\}$ that is a set of elements to which x is similar [34.4]. If R is reflexive, we can have a cover $\mathcal{F} = \{R(x) \mid x \in U\}$. Since a similarity relation R should satisfy the reflexivity, the situation with R is a special case of the situation with a cover \mathcal{F} .

On the other hand, when a cover $\mathcal{F} = \{F_1, F_2, \dots, F_n\}$ is given, we face a problem how we can produce a similarity relation R such that $\mathcal{F} = \{R(x) \mid x \in U\}$. Only if there is a unique F_i such that $x \in F_i$ for any $x \in U$, we can solve this problem. However, this case is nothing but a case when \mathcal{F} is a partition. Thus, there is no R satisfies $\mathcal{F} = \{R(x) \mid x \in U\}$ whenever \mathcal{F} is not a partition.

Hence, under a finite universe U , a problem setting with a cover \mathcal{F} seems to be more general than that with a similarity relation R . This is true in an interpretation of rough sets as approximations by means of elementary sets. However, each elementary set F_i of \mathcal{F} is not associated with an element $x \in U$. Because of this fact, we cannot always say that a cover \mathcal{F} is more general than a similarity relation R .

Finally, we should note that R_* , R_*^1 and R_*^2 are no longer equivalent in both generalized settings. Neither R^* , R_1^* nor R_2^* are. We have $R^*(X) = U - R_*(U - X)$, $R_i^*(X) = U - R_*^i(U - X)$, $i = 1, 2$ and, under the reflexivity of R , we obtain $R_*^2(X) \subseteq R_*(X) \subseteq R_*^1(X)$ and $R_1^*(X) \subseteq R^*(X) \subseteq R_2^*(X)$.

Table 34.2. Fundamental properties of $\mathcal{F}_*^1(X)$ and $\mathcal{F}_1^*(X)$

(i)	$\mathcal{F}_*^1(X) \subseteq X \subseteq \mathcal{F}_1^*(X)$
(ii)	$\mathcal{F}_*^1(\emptyset) = \mathcal{F}_1^*(\emptyset) = \emptyset, \mathcal{F}_*^1(U) = \mathcal{F}_1^*(U) = U$
(iii)	$\mathcal{F}_*^1(X \cap Y) \subseteq \mathcal{F}_*^1(X) \cap \mathcal{F}_*^1(Y), \mathcal{F}_1^*(X \cup Y) \supseteq \mathcal{F}_1^*(X) \cup \mathcal{F}_1^*(Y)$
(iv)	$X \subseteq Y$ implies $\mathcal{F}_*^1(X) \subseteq \mathcal{F}_*^1(Y), X \subseteq Y$ implies $\mathcal{F}_1^*(X) \subseteq \mathcal{F}_1^*(Y)$
(v)	$\mathcal{F}_*^1(X \cup Y) \supseteq \mathcal{F}_*^1(X) \cup \mathcal{F}_*^1(Y), \mathcal{F}_1^*(X \cap Y) \subseteq \mathcal{F}_1^*(X) \cap \mathcal{F}_1^*(Y)$
(vi)	$\mathcal{F}_*^1(U - X) = U - \mathcal{F}_1^*(X), \mathcal{F}_1^*(U - X) = U - \mathcal{F}_*^1(X)$
(vii)	$\mathcal{F}_*^1(\mathcal{F}_*^1(X)) = \mathcal{F}_*^1(X), \mathcal{F}_*^1(X) \subseteq \mathcal{F}_1^*(\mathcal{F}_*^1(X)) \subseteq \mathcal{F}_1^*(X),$ $\mathcal{F}_1^*(\mathcal{F}_1^*(X)) = \mathcal{F}_1^*(X), \mathcal{F}_1^*(X) \supseteq \mathcal{F}_*^1(\mathcal{F}_1^*(X)) \supseteq \mathcal{F}_*^1(X)$

34.4 Approximation by Means of Elementary Sets

In interpretation of rough sets as approximations of sets by means of elementary sets, we assume a general setting, i.e., a case when a cover $\mathcal{F} = \{F_1, F_2, \dots, F_n\}$ is given. In this case, we should consider $\mathcal{F}_*^1(X), \mathcal{F}_*^2(X), \mathcal{F}_1^*(X)$ and $\mathcal{F}_2^*(X)$ defined by (34.2)–(34.5) substituting F_i for $R(x)$, respectively.

We can prove $\mathcal{F}_*^2(X) \subseteq \mathcal{F}_*^1(X) \subseteq X$ and $X \subseteq \mathcal{F}_1^*(X) \subseteq \mathcal{F}_2^*(X)$. Hence, $\mathcal{F}_*^1(X)$ and $\mathcal{F}_1^*(X)$ are better lower and upper approximations of X . Thus, we define a rough set of X under \mathcal{F} by a pair of $\mathcal{F}_*^1(X)$ and $\mathcal{F}_1^*(X)$.

For $\mathcal{F}_*^1(X)$ and $\mathcal{F}_1^*(X)$, we have fundamental properties listed in Table 34.2. By the lack of disjointedness between F_i and F_j ($i \neq j$), none of $\mathcal{F}_*^1(X \cap Y) \supseteq \mathcal{F}_*^1(X) \cap \mathcal{F}_*^1(Y), \mathcal{F}_1^*(X \cup Y) \subseteq \mathcal{F}_1^*(X) \cup \mathcal{F}_1^*(Y), \mathcal{F}_*^1(X) \supseteq \mathcal{F}_1^*(\mathcal{F}_*^1(X))$ and $\mathcal{F}_1^*(X) \supseteq \mathcal{F}_*^1(\mathcal{F}_1^*(X))$ always holds.

Complete definability of X in the setting where \mathcal{F} is given can be defined as

- (a) X is \mathcal{F} -inner completely definable if and only if $\mathcal{F}_*^1(X) = X$ is satisfied.
- (b) X is \mathcal{F} -outer completely definable if and only if $\mathcal{F}_1^*(X) = X$ is satisfied.
- (c) X is \mathcal{F} -completely definable if and only if X is \mathcal{F} -inner completely definable and at the same time \mathcal{F} -outer completely definable.

34.5 Distinction among Three Regions

Let X be a set corresponding to a vague concept. Then the elements of X are not always agreed by all people. A given set X includes elements on whose memberships all people agree and also elements on whose memberships some people argue. Elements of X can be divided into unquestionable and questionable members. In such a case, rough sets can be applied to classify elements into three categories: positive members, negative members and boundary members.

Let \underline{X} and \overline{X} be sets of positive members and possible members, respectively. Here ‘possible members’ are composed of positive and boundary

Table 34.3. Fundamental properties of $R_*^3(X)$ and $R_3^*(X)$

(i)	$R_*^3(X) \subseteq X \subseteq R_3^*(X)$
(ii)	$R_*^3(\emptyset) = R_3^*(\emptyset) = \emptyset, R_*^3(U) = R_3^*(U) = U$
(iii)	$R_*^3(X \cap Y) = R_*^3(X) \cap R_*^3(Y), R_3^*(X \cup Y) = R_3^*(X) \cup R_3^*(Y)$
(iv)	$X \subseteq Y$ implies $R_*^3(X) \subseteq R_*^3(Y), X \subseteq Y$ implies $R_3^*(X) \subseteq R_3^*(Y)$
(v)	$R_*^3(X \cup Y) \supseteq R_*^3(X) \cup R_*^3(Y), R_3^*(X \cap Y) \subseteq R_3^*(X) \cap R_3^*(Y)$
(vi)	$R_*^3(U - X) = U - R_3^*(X), R_3^*(U - X) = U - R_*^3(X)$
(vii)	$R_3^*(R_*^3(X)) \subseteq X$ does not always hold, $R_*^3(R_3^*(X)) \supseteq X$ does not always hold.

members. A given X should satisfy $\underline{X} \subseteq X \subseteq \overline{X}$. We assume that only elements which are similar to a member of \underline{X} can be regarded as possible members. Then we have

$$\overline{X} \subseteq \bigcup_{y \in \underline{X}} R(y) = \{x \mid R^{-1}(x) \cap \underline{X} \neq \emptyset\}. \tag{34.6}$$

Since $U - \underline{X} = \overline{(U - X)}$ and $\underline{(U - X)} = U - \overline{X}$, we also have

$$\underline{X} \supseteq U - \bigcup_{y \notin \overline{X}} R(y) = \{x \mid R^{-1}(x) \subseteq \overline{X}\}. \tag{34.7}$$

In our problem setting, we know X such that $\underline{X} \subseteq X \subseteq \overline{X}$, only. We obtain a lower approximation of \underline{X} and an upper approximation of \overline{X} as follows:

$$R_*^3(X) = \{x \mid R^{-1}(x) \subseteq X\}, \quad R_3^*(X) = \{x \mid R^{-1}(x) \cap X \neq \emptyset\}. \tag{34.8}$$

The fundamental properties of $R_*^3(X)$ and $R_3^*(X)$ are listed in Table 34.3. By the interpretation of lower and upper approximations, $R_*^3(R_*^3(X))$ and $R_3^*(R_3^*(X))$ are nonsense. Comparing to Table 34.2, property (iii) is preserved in Table 34.3. The preservation of property (vii) in Table 34.3 is worse than that in Table 34.2.

From (34.6) and (34.7), a family of consistent lower regions is given as $\mathcal{X} = \{\underline{X} \mid R_*^3(X) \subseteq \underline{X} \subseteq X \subseteq R_3^*(\underline{X})\}$. Similarly, a family of consistent upper regions is given as $\mathcal{X} = \{\overline{X} \mid R_*^3(\overline{X}) \subseteq X \subseteq \overline{X} \subseteq R_3^*(X)\}$. From (34.6) and (34.7) again, $\overline{X} \subseteq R_3^*(\underline{X})$ and $R_*^3(\overline{X}) \subseteq \underline{X}$ should be satisfied. Thus, a family of consistent pairs of positive and possible regions is obtained as $\mathcal{C} = \{(\underline{X}, \overline{X}) \mid \underline{X} \in \mathcal{X}, \overline{X} \in \mathcal{X}, \overline{X} \subseteq R_3^*(\underline{X}), R_*^3(\overline{X}) \subseteq \underline{X}\}$. Note that $(X, X) \in \mathcal{C}$ always holds.

We can define the definiteness of X under a similarity relation R as follows:

- (d) X is said to be R -definite if and only if \mathcal{C} is a singleton.
- (e) X is said to be R -inner definite if and only if $\underline{X} = X$ for all $(\underline{X}, \overline{X}) \in \mathcal{C} \neq \emptyset$.
- (f) X is said to be R -outer definite if and only if $\overline{X} = X$ for all $(\underline{X}, \overline{X}) \in \mathcal{C} \neq \emptyset$.

When X is R -definite, we have $\mathcal{C} = \{(X, X)\}$. This implies that the concept expressed by X is precise. X is R -definite whenever X is R -inner

and outer definite. X is R -inner definite if $R_*^3(X) = X$ and X is R -outer definite if $R^*_3(X) = X$. When R is an equivalence relation, X is R -definite if and only if $R_*^3(X) = R^*_3(X) = X$. Thus, the definiteness corresponds to complete definability.

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35. Two Procedures for Dependencies among Attributes in a Table with Non-deterministic Information: A Summary

Hiroshi Sakai

Department of Computer Engineering, Kyushu Institute of Technology,
Tobata, Kitakyushu 804, Japan sakai@comp.kyutech.ac.jp

The data dependency among attributes is very important for the rule generation. So far, we proposed a dependency among attributes in a table with non-deterministic information, and developed some important algorithms. According to these algorithms, a procedure for dependencies has been implemented. This paper proposes new algorithms and enhances the implemented procedure. In two procedures, the manipulation of equivalence relations takes an important role.

35.1 Preliminary

The rough set theory has been widely applied in the research areas in artificial intelligence such as knowledge, imprecision, vagueness, learning, induction, and so on [35.2], since it was proposed by Pawlak in around 1980.

According to [35.2], we define a *Deterministic Information System* $DIS = (OB, AT, \{VAL_a | a \in AT\}, f)$, where OB is a finite set whose elements we call *objects*, AT is a finite set whose elements we call *attributes*, VAL_a is a finite set whose elements we call *attribute values* and f is a mapping such that $f : OB \times AT \rightarrow \cup_a VAL_a$ which we call a *classification function*. For every object $x, y (x \neq y) \in OB$, if $f(x, a) = f(y, a)$ for every $a \in AT$, we say *there is a relation for x and y* , which becomes an equivalence relation over OB . We express an equivalence class with an object x as $[x]$. If a set $X (\subset OB)$ is the union of some equivalence classes, we say X is *definable*. Otherwise we say X is *rough*.

Suppose $CON (\subset AT)$ and $DEC (\subset AT)$ denote *condition attributes* and *decision attributes*, respectively. We say that two objects $x, y (x \neq y) \in OB$ are *consistent for CON and DEC* , if $f(x, a) = f(y, a)$ for every $a \in CON$ then $f(x, a) = f(y, a)$ for every $a \in DEC$. In case every object is consistent with other objects in a DIS , we say the DIS is *consistent for CON and DEC* , and we see there exists a dependency between CON and DEC . Furthermore, we see every tuple restricted to CON and DEC is a rule. In case a DIS is not consistent for CON and DEC , a ratio $|POS_{CON}(DEC)|/|OB|$ is applied to measure the degree of dependency. Here, the set $POS_{CON}(DEC) = \cup \{L \in eq(CON) | \text{there exists such } M \in eq(DEC) \text{ as } L \subset M\}$ is called the *positive region*.

35.2 Definitions of NISs

We show a framework of the *Non-deterministic Information System NIS* according to [35.1]. We define a $NIS = (OB, AT, \{VAL_a | a \in AT\}, g)$, where g is a mapping such that $g : OB \times AT \rightarrow P(\cup_a VAL_a)$ (A power set of $\cup_a VAL_a$). Every set $g(x, a)$ is interpreted as that there is an actual value in this set but we do not know it. This is called the *unknown interpretation* for the incomplete information. Especially if we do not know the attribute value at all, we consider $g(x, a) = VAL_a$. This is called the *null value interpretation*.

As for *NISs*, Lipski showed the modal question-answering. Orłowska and Pawlak discussed the modal concept, especially the axiomatization of the logic in *NISs*. Grzymala-Busse surveyed the unknown attribute values and studied the learning from examples with unknown attribute values.

Example 1. Let's consider the next *NIS* and the problem.

Table 35.1. A Table of a *NIS*

<i>OB</i>	<i>A</i>	<i>B</i>	<i>C</i>
1	3	1	1
2	5	{2, 4}	2
3	{1, 4, 5}	5	4
4	4	5	2
5	3	5	2
6	4	5	{1, 3}
7	5	4	1
8	1	{1, 3, 4}	1

Problem: In Table 1, do we see there exists a dependency between $\{A, B\}$ and $\{C\}$? Generally, how do we deal with the dependency in every *NIS*, and how effectively do we calculate the dependency in *NIS*?

For this problem, we consider every possible case in the *NIS*. In Table 1, $36 (= 3 \times 2 \times 3 \times 2)$ possible *DISs* are derived by replacing $g(x, a)$ with an element in $g(x, a)$. Generally in every *NIS*, we call such a *DIS* a *derived DIS from a NIS*. According to derived *DISs*, we propose a new dependency in a *NIS*.

A Proposal of New Dependency in a NIS

Suppose there exist a *NIS*, all derived DIS_1, \dots, DIS_m , condition attributes *CON*, decision attributes *DEC*. For two threshold values val_1 and val_2 ($0 \leq val_1, val_2 \leq 1$), if the following conditions hold then we see *there exists a dependency between CON and DEC in the NIS*.

- (1) Suppose a set $P = \{DIS_i | DIS_i (1 \leq i \leq m)\}$ is consistent for *CON* and *DEC*. For this set P , $|P|/m > val_1$.
- (2) $\min_i \{\text{degree of dependency in } DIS_i | (1 \leq i \leq m)\} > val_2$.

This new dependency is calculated by each degree of dependency in every derived *DIS*. In Example 1, suppose $val_1 = 0.8$ and $val_2 = 0.8$. The condition (1) requires $|P|/36 > 0.8$, namely more than 29 derived *DIS* must be consistent. The condition (2) requires the minimal degree of dependency is

more than 0.8. As for the implementation, the simple way is to calculate the degree of dependency for all derived *DISs*. However, this way is not suitable for *NISs* with large number of derived *DISs*. We rely on another way for the implementation.

35.3 A Way to Obtain All Possible Equivalence Relations

We call every equivalence relation in a derived *DIS* a *possible equivalence relation (pe-relation)*, and call every element in a pe-relation a *possible equivalence class (pe-class)*.

Proposition 1. Suppose there exist a *NIS* and a set $X (\subset OB)$. If there exist subsets of OB, CL_1, \dots, CL_m satisfying (1) and (2), X is definable in this *NIS*.

(1) $\cup_i CL_i = X$.

(2) $\{CL_1, \dots, CL_m\}$ is a subset of a pe-relation.

According to this proposition, we check the definability of a set by finding sets CL_1, \dots, CL_m . We have already realized this program. In order to obtain all pe-relations, we put $X = OB$. Then, all pe-relations are obtained as a side effect of checking the definability of the set OB [35.3].

35.4 Procedure 1 for Dependencies

Let's $eq(CON)$ and $eq(DEC)$ be equivalence relations for the condition and decision attributes in a *DIS*, respectively. In this case, it is easy to calculate the degree of dependency $|POS_{CON}(DEC)|/|OB|$ by $eq(CON)$ and $eq(DEC)$ [35.3]. This property is applied to all pe-relations in every *NIS*, and the new dependency is calculated. The following is a procedure for it.

Procedure 1

(Step 1) Prepare a data file and an attribute file. The attributes *CON* and *DEC* are defined in this attribute file.

(Step 2) Translate them into internal expressions.

(Step 3) Pick up all pe-relations for *CON* and *DEC*, respectively.

(Step 4) Calculate criteria values by those relations.

The following is the real execution of Step 4 in Example 1. Here, $CON = \{A, B\}$ and $DEC = \{C\}$.

```
% dependency
Dependency Check [1,2] => [3]
CRITERION 1   Degree of consistent DISs: 0.0
CRITERION 2   Minimal Degree of Dependency: 0.375
               Maximal Degree of Dependency: 0.750
EXEC.TIME = 0.030 (sec)
%
```

35.5 Procedure 2 for Dependencies

Suppose it is necessary to check several kinds of dependencies in a *NIS*. In Procedure 1, the *CON* and *DEC* must be specified in Step 1. So, it is necessary to do a sequence from Step 1 to Step 4 for each dependency. To make matters worse, Step 3 is time-consuming. In such a situation, we revised Procedure 1 to Procedure 2. In Procedure 2, a merging algorithm for equivalence relations is employed. Suppose $eq(A_1)$ and $eq(A_2)$ be equivalence relations for $A_1, A_2 (\subset AT)$, respectively. The equivalence relation $eq(A_1 \cup A_2)$ is $\{M \subset OB | M = L_1 \cap L_2 (\neq \emptyset) \text{ for some } L_1 \in eq(A_1) \text{ and } L_2 \in eq(A_2)\}$. Namely, an equivalence relation for any set of attributes can be produced from $eq(a) (a \in AT)$.

Procedure 2

(EStep 1) Prepare data file.

(EStep 2) Translate them to internal expressions for each attribute.

(EStep 3) Make all *pe*-relations for each attribute.

(EStep 4) Fix condition attributes *CON*, decision attributes *DEC*, and produce all *pe*-relations for *CON* and *DEC*, respectively.

(EStep 5) Calculate two criteria values by those relations.

In this procedure, it is enough to execute EStep 2 and EStep 3 only once. It is enough to do EStep 4 and EStep5 for each pair of *CON* and *DEC*.

35.6 Execution Time of Every Method

Now, let us see the execution time of each method to calculate the degree of dependency. Four *NISs* in Table 2 are used, and the dependencies between $\{A, B, C\}$ and $\{D\}$ are calculated. Every method is implemented on a workstation with the 450MHz UltraSparc CPU by Prolog and C language.

Table 35.2. Definitions of *NISs*

<i>NIS</i>	$ OB $	$ AT $	$ Val_a (a \in AT)$	<i>Derived_DISs</i>
<i>NIS</i> ₁	10	4	10	864
<i>NIS</i> ₂	100	4	10	1944
<i>NIS</i> ₃	300	4	10	3888
<i>NIS</i> ₄	1000	4	100	7776

According to Table 3, it is known that Step 3 in Procedure 1 and EStep 3 in Procedure 2 are the most time-consuming. These two steps pick up *pe*-relations from internal expressions. The execution time of Step 4, EStep4 and EStep 5 are very small for the total execution time in Table 4. As for *NIS*₁ and *NIS*₂ in Table 4, each execution time of the simple method for a *DIS* was 0.00 (sec).

Suppose it is necessary to check five kinds of dependencies among attributes in *NIS*₄. In the simple method and Procedure 1, it is necessary to do all

Table 35.3. The execution time(sec) of Procedure 1 and 2 for checking the dependency $\{A, B, C\}$ and $\{D\}$. Step 2, Step 3, EStep 2 and EStep 3 are realized by Prolog, Step 4, EStep 4 and EStep 5 by C.

<i>NIS</i>	<i>Step2</i>	<i>Step3</i>	<i>Step4</i>	<i>EStep2</i>	<i>EStep3</i>	<i>EStep4</i>	<i>EStep5</i>
<i>NIS</i> ₁	0.05	0.17	0.06	0.07	0.16	0.01	0.05
<i>NIS</i> ₂	0.48	0.84	0.07	0.70	2.07	0.10	0.12
<i>NIS</i> ₃	2.60	8.67	0.07	3.61	5.96	1.03	1.00
<i>NIS</i> ₄	26.57	122.45	0.14	31.32	45.70	0.82	1.37

Table 35.4. The total execution time(sec) of the simple method, Procedure 1 and 2 for checking the dependency $\{A, B, C\}$ and $\{D\}$. The 2nd column simple shows such a value as (execution time to calculate the degree of dependency in a derived *DIS*) \times (the number of all derived *DIS*s).

<i>NIS</i>	<i>Total(Simple)</i>	<i>Total(Procedure1)</i>	<i>Total(Procedure2)</i>
<i>NIS</i> ₁	—	0.28	0.29
<i>NIS</i> ₂	—	1.39	2.99
<i>NIS</i> ₃	38.88	11.34	11.60
<i>NIS</i> ₄	933.12	149.16	79.21

steps. Therefore, it will take about 4665.60(=933.12 \times 5)(sec) by the simple method and about 745.80(=149.16 \times 5)(sec) by Procedure 1, respectively. In Procedure 2, it is enough to do EStep 2 and EStep 3 only once. It is enough to repeat the EStep 4 and EStep 5 for 5 times. In this case, it will take about 87.97 (=31.32+45.70+5 \times (0.82+1.37))(sec).

35.7 Concluding Remarks

This paper proposed a dependency in non-deterministic information systems and two procedures for calculating this new dependency. We conclude that *for checking a dependency in small size data like NIS₁ and NIS₂, every three method will be applicable. However for large size data like NIS₄, Procedure 1 and 2 are applicable. It will be hard to apply the simple method. For checking several kinds of dependencies, Procedure 2 is much better than Procedure 1.*

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36. An Application of Extended Simulated Annealing Algorithm to Generate the Learning Data Set for Speech Recognition System

Chi-Hwa Song and Won Don Lee

Dept. of Computer Science, Chungnam Nat'l Univ. Daejeon 305-764, KOREA,
 (chsong@cnu.ac.kr) (wdlee@cnu.ac.kr)

Abstract. *In this paper, we suggest a method of data extraction for constructing the speech recognition system. The proposed algorithm is based on the Extended Simulated Annealing(ESA) algorithm. We have used Korean text data, drawn randomly from the internet. The Korean LDS built by the proposed algorithm has the equiprobable distribution among Korean alphabets.*

36.1. Introduction

The speech recognition systems are trained using the learning data set that is collected or extracted from appropriate data bank. Up to now, however, we have no criterion whether the learning data set is proper for the speech recognition system that we build. Worse, it is hard to train the speech recognition system as the number of the training data is increasing. To make the training effective, we need enough training data so that the recognition system does not rely on some specific words and alphabets. The suitable training data are required in order to set up the module with the high reliability. We believe that a right training data should be such that each alphabet be manifested equiprobably. We propose a method of extracting LDS(learning data set) that has the equiprobability in the pattern domain with as few elements as possible.

36.2. Domain Definition for LDS Extraction

Table 1. Korean alphabet table

	Initial sound	Medial vowels	Final consonant		Initial sound	Medial vowels	Final consonant
0	ㄱ	ㅏ	FILL	14	ㅈ	ㅑ	ㅇ
1	ㅋ	ㅓ	ㄱ	15	ㅊ	ㅕ	ㅇ
2	ㆁ	ㅗ	ㅋ	16	ㅌ	ㅓ	ㅇ
3	ㆁ	ㅛ	ㆁ	17	ㅍ	ㅑ	ㅇ
4	ㄷ	ㅜ	ㄴ	18	ㅍ	ㅕ	ㅇ
5	ㅌ	ㅠ	ㄴ	19	ㅑ	ㅑ	ㅇ
6	ㅍ	ㅡ	ㅇ	20	ㅑ	ㅑ	ㅇ
7	ㅍ	ㅣ	ㅇ	21	ㅑ	ㅑ	ㅇ
8	ㅍ	ㅓ	ㅇ	22	ㅑ	ㅑ	ㅇ
9	ㅍ	ㅓ	ㅇ	23	ㅑ	ㅑ	ㅇ
10	ㅍ	ㅓ	ㅇ	24	ㅑ	ㅑ	ㅇ
11	ㅍ	ㅓ	ㅇ	25	ㅑ	ㅑ	ㅇ
12	ㅍ	ㅓ	ㅇ	26	ㅑ	ㅑ	ㅇ
13	ㅍ	ㅓ	ㅇ	27	ㅑ	ㅑ	ㅇ

A Korean character is composed of 19 initial sounds, 21 medial vowels and 27 final consonant. Here, The final consonant is omissible(FILL), so we can use total 28 characters as final consonants. Table 1 shows Korean alphabets. We collected the candidate data at random in the internet for extracting the LDS.

The weight of a word for extraction is related to the appearance frequency of a word and the entropy of Korean alphabetic distribution in those words. If a word occurrence is more often than others in the candidate data set, then we select it as a "molecule" of learning data set and our algorithm tries to get the highest entropy value of Korean alphabet distribution.

36.3. The Numerical Formula for LDS Extraction

$$Benefit(B) = \alpha * (\sum_i \mu 1_i N_i + \sum_j \mu 2_j N_j) - \beta * E$$

$\mu 1$: weight of occurrence frequency

$\mu 2$: weight of the length of word

N : the number of words having the same occurrence frequency

M : the number of words having the same length

E : the entropy of learning dataset in Korean alphabets

$$E = -\sum P(k) * \text{Log}_{10} P(k)$$

$Benefit(B)$ is the criterion that we want to maximize. Learning data set consists of the words which make the set have maximum B . $\mu 1$ is the weight of a word. It is in proportional to the appearance frequency in the text. For example, in the whole data, if the word '학교'[hakgyo (school)] is repeated 2 times and the word '학생'[hakseang(student)] is repeated 1 time, we select the word '학교' to include '학' in the LDS. $\mu 2$ is used as a parameter to select the proper length of word. Generally, short words appear recurrently in the Korean text. If we divide words by the blank in the text, the letters like '수', '가', '할', '때', '그', '저' etc. appears more often than other words.

In the experiment, we set the average length of word is 3 and in that case it has the biggest $\mu 2$. If the word is longer or shorter than 3-letter-length, it is selected in the candidate data set with low probability. Fig1 and Fig2 represent the weights of $\mu 1$ and $\mu 2$ used in the experiment.

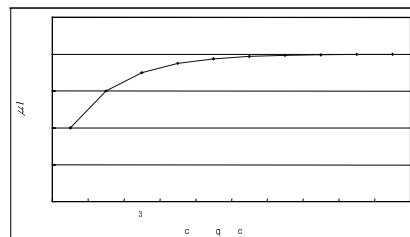


Fig. 1. $\mu 1$

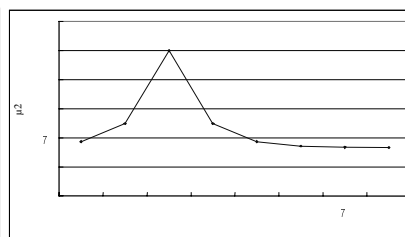


Fig. 2. $\mu 2$

M shows the number of words that have the same occurrence-frequency and N shows the number of words that have the same length. If the word '학교' appears 3 times in the whole data, then $\mu 1$ is to be 1.75 as Fig 1. Likewise, if the words

with $\mu 1$ values equal to 1.75 appear 100 times in the LDS, then N is set to 100. $\mu 2$ of the words with length 3, such as '우리집', '강아지', '어린이' is set to 1. And M is the number of words with $\mu 2$ value set to 1 in that case. The constants α, β determine the importance between two terms. k is the index of Korean alphabets and is the probability of Korean alphabet k in the whole text data. Therefore E shows the entropy of Korean alphabet in the selected words.

As a whole, the final result of LDS consists of the words with the appropriate length and also with the frequently appeared words and the set has the maximum entropy value.

36.4. The Algorithm for Extraction of LDS

The pre-processing is done;

1. Divide the whole text data into the unit(word) that we intend to recognize.
2. Remove the repeated words and calculate the values of $\mu 1, \mu 2$
3. calculate the occurrence of each alphabet in the whole words.

The data set extraction algorithm based on ESA:

$T(o)$ = initial temperature ($T(o) > T(i) > T(f)$)

$T(f)$ = final temperature

D = annealing schedule parameters close to 1.

LDS_o = a stable learning data set, it starts with the initial LDS.

LDS_n = a perturbed LDS_o

<pre> Annealing() { do { do { switch (Random[0,1,2]) { case 0 : select a word w outside of LDSo LDSn = LDSo + w break case 1 : select a word w in the LDSo LDSn = LDSo - w break case 2 : select a word w1 outside of LDSo select a word w2 in of LDSo </pre>	<pre> LDSn = LDSo + w1 - w2 break } DecideAcceptOfLDSn() }while (unstable state) T(i) *= D } while(T > F) } DecideAcceptOfLDSn() { calculate $\Delta B = B_{\text{enefit of } LDS_n} - B_{\text{enefit of } LDS_o}$ if ($\Delta B > 0.0$) LDSo = LDSn; else-if $\exp(-\Delta B/T(i)) < \text{Random}[0,1]$ LDSo = LDSn; else Reject the LDSn; } </pre>
---	--

The LDS extraction Algorithm is founded on ESA[Wdlee,1997]. We obtain the candidate data set through the pre-process as follows. After making candidate data set, we choose some arbitrary words in the set to build the initial LDS and compute its initial benefit(B).

36.5. Experimental and Result

The data used in the experiment are 16871 words in total after removing the repeated words, collected in the internet at random. In the experiment, the benefit of data set does not depend much on the values of α and β . But we can get the maximum benefit when the number of the words is about 4950. The following Fig 3 represents the change of Energy(-Benefit) with time when 4219 randomly chosen words are used to set up the initial data set. Finally, the algorithm extracts 4946 words when the value of α is 0.1 and β is 100.

In the figure 3, the energy is decreasing and finally converges to a value after some iteration.

Although we change the initial data set to include more than 1000 words or less than 1000 words, the final result does not change that much.

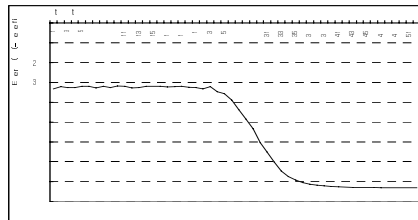


Fig. 3. The change of *-Benefit*

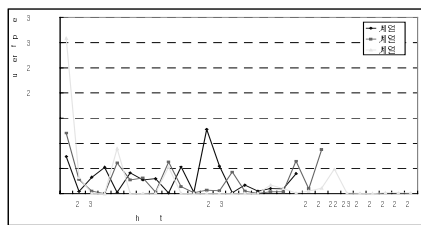


Fig. 4. Alphabets appeared in initial data

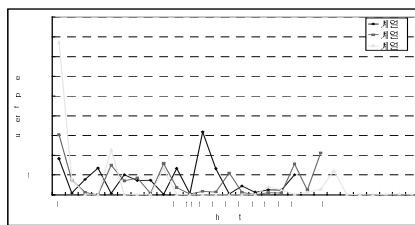


Fig. 5. Alphabet after final calculation in the LDS

Fig 4 represents the total number of alphabets in the candidate LDS. Line 1 represents initial sound alphabets, line 2 represent the medial vowels sound alphabets and the line3 represents the final consonant alphabets. In Fig 4, (the first initial sound) appeared more than 30000 times and some alphabets didn't appear in the initial data set. When the algorithm is applied to such an initial data set, the oc-

curred less than 8000 times and the data set becomes equiprobable on each alphabet. We can get a training data set with a minimal number of words with this algorithm, thereby saving the time to train the recognition system with a large number of words. The system protects the recognition system from being trained by some specific sound or syllable and thus can maximize its reliability.

36.6. Conclusion

In the experiment, α and β values are set by trial and error. To get the α and β , we experiment on the possible combinations about 5 times in the same condition. And the proposed algorithm is found to be sensitive to those values. Some Korean alphabets are more often than others in the usual Korean text, but the algorithm can reduce this unbalance. The learning data set(LDS), extracted by the proposed algorithm has the regular distribution in the domain of Korean alphabets. The proposed algorithm makes improvement in the reliability through the reformation of the speech recognition system.

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37. Generalization of Rough Sets with α -Coverings of the Universe Induced by Conditional Probability Relations

Rolly Intan¹, Masao Mukaidono¹, and Y.Y. Yao²

¹ Meiji University, Kawasaki-shi, Kanagawa-ken, Japan

² University of Regina, Regina, Saskatchewan, Canada S4S 0A2

Standard rough sets are defined by a partition induced by an equivalence relation representing discernibility of elements. Equivalence relations may not provide a realistic view of relationships between elements in real-world applications. One may use coverings of, or non-equivalence relations on, the universe. In this paper, the notion of *weak fuzzy similarity relations*, a generalization of fuzzy similarity relations, is used to provide a more realistic description of relationships between elements. A special type of weak fuzzy similarity relations called conditional probability relation is discussed. Generalized rough set approximations are proposed by using α -coverings of the universe induced by conditional probability relations.

37.1 Introduction

The theory of rough sets plays essential roles in many applications of data mining and knowledge discovery [37.6]. It offers a mathematical model and tools for discovering hidden patterns in data, recognizing partial or total dependencies in data bases, removing redundant data, and many others [37.4, 37.6]. Rough set theory generalizes classical set theory by offering an alternative formulation of sets with imprecise boundaries. A rough set may be viewed as an approximate representation of a given crisp set in terms of two subsets derived from a partition on the universal set [37.3]. The two subsets are called a lower approximation and an upper approximation.

Although rough set theory built on equivalence relation has the advantage of being easy to analyze, it may not be a widely applicable model as equivalence relations may not provide a realistic view of relationships between elements in real world. Coverings of, non-equivalence relations, on the universe may be used to provide a more realistic model of rough sets. A covering of the universe, $C = \{C_1, \dots, C_n\}$, is a family of subset of non-empty universe U such that $U = \bigcup\{C_i \mid i = 1, \dots, n\}$. The sets in $C(x)$ may describe *different types* or various degrees of similarity between elements of U . The interpretation and construction of subsets in a covering are some of the fundamental issues of covering based formulation of rough set theory. Crisp and fuzzy binary relations may be used for such purposes. In general, relationships between elements in real-world applications may not necessarily be symmetric or transitive. Recently, *conditional probability relations* [37.1] was introduced

for representing such non-equivalence relationships between elements. Conditional probability relations may be considered as a generalization of fuzzy similarity relations.

The main objective of this paper is to generalize the standard concept of rough sets by coverings of the universe. Conditional probability relations are used in the construction of coverings. Rough set approximations are introduced based on α -coverings of the universe induced by the α -cuts of a conditional probability relation. The proposed rough sets may be considered as generalized fuzzy rough sets [37.7].

37.2 Conditional Probability Relations

The concept of *conditional probability relations* was introduced in the context of fuzzy relational databases [37.1]. It may be considered as a concrete example of *weak fuzzy similarity relation*, which in turn is a special type of fuzzy binary relation.

Definition 37.2.1. A *fuzzy similarity relation* is a mapping, $s : U \times U \rightarrow [0, 1]$, such that for $x, y, z \in U$,

- (a) Reflexivity : $s(x, x) = 1$,
- (b) Symmetry : $s(x, y) = s(y, x)$,
- (c) Max–min transitivity : $s(x, z) \geq \max_{y \in U} \min[s(x, y), s(y, z)]$.

Definition 37.2.2. A *weak fuzzy similarity relation* is a mapping, $s : U \times U \rightarrow [0, 1]$, such that for $x, y, z \in U$,

- (a) Reflexivity : $s(x, x) = 1$,
- (b) Conditional symmetry : if $s(x, y) > 0$ then $s(y, x) > 0$,
- (c) Conditional transitivity : if $s(x, y) \geq s(y, x) > 0$ and $s(y, z) \geq s(z, y) > 0$ then $s(x, z) \geq s(z, x)$.

Definition 37.2.3. A *conditional probability relation* is a mapping, $R : U \times U \rightarrow [0, 1]$, such that for $x, y \in U$,

$$R(x, y) = P(x | y) = P(y \rightarrow x) = \frac{|x \cap y|}{|y|},$$

where $R(x, y)$ means the degree y supports x or the degree y is similar to x .

By definition, a fuzzy similarity relation is regarded as a special case (or type) of weak fuzzy similarity relation, and a conditional probability relation is an example of weak fuzzy similarity relations. The conditional probability relations may be used as a basis of representing degree of similarity relationships between elements in the universe U . In the definition of conditional

probability relations, the probability values may be estimated based on the semantical relationships between elements by using the epistemological or subjective view of probability theory. When objects in U are represented by sets of features or attributes as in the case of binary information tables, we have a simple procedure for estimating the conditional probability relation as shown in Definition 37.2.3, where $|\cdot|$ denotes the cardinality of a set.

The notion of binary information tables can be easily generalized to fuzzy information tables by allowing a number in the unit interval $[0, 1]$ for each cell of the table. The number is the degree to which an element has a particular attribute. Each object is represented as a fuzzy set of attributes. The degree of similarity two objects can be calculated by a conditional probability relation on fuzzy sets [37.1, 37.2]. In this case, $|x| = \sum_{a \in At} \mu_x(a)$, where μ_x is membership function of x over a set of attribute At , and intersection is defined by minimum.

Definition 37.2.4. *Let μ_x and μ_y be two fuzzy sets over a set of attribute At for two elements x and y of a universe of objects U . A fuzzy conditional probability relation is defined by:*

$$R(x, y) = \frac{\sum_{a \in At} \min\{\mu_x(a), \mu_y(a)\}}{\sum_{a \in At} \mu_y(a)}.$$

It can be easily verified that R satisfies properties of a weak fuzzy similarity relation. Additional properties of similarity as defined by conditional probability relations can be found in [37.1].

37.3 Generalized Rough Sets Approximation

From weak fuzzy similarity relations and conditional probability relations, coverings of the universe can be defined and interpreted. The standard concept of rough sets can thus be generalized based on coverings of universe.

Definition 37.3.1. *Let U be a non-empty universe, and R be a conditional probability relation on U . For any element $x \in U$, $R_s^\alpha(x)$ and $R_p^\alpha(x)$ are defined as the set of elements that support x and the set of elements that are supported by x , respectively, to a degree of at least $\alpha \in [0, 1]$, as follows:*

$$R_s^\alpha(x) = \{y \in U \mid R(x, y) \geq \alpha\}, \quad R_p^\alpha(x) = \{y \in U \mid R(y, x) \geq \alpha\}.$$

The set $R_s^\alpha(x)$ can also be interpreted as consisting of elements that are similar to x , while $R_p^\alpha(x)$ consisting of elements to which x is similar. By the reflexivity, it follows that we can construct two covering of the universe, $\{R_s^\alpha(x) \mid x \in U\}$ and $\{R_p^\alpha(x) \mid x \in U\}$. By extending standard rough sets, we obtain two pairs of generalized rough set approximations.

Definition 37.3.2. For a subset $A \subseteq U$, we define two pairs of generalized rough set approximations:

(i) *element-oriented generalization:*

$$L_e^\alpha(A) = \{x \in U \mid R_s^\alpha(x) \subseteq A\},$$

$$U_e^\alpha(A) = \{x \in U \mid R_s^\alpha(x) \cap A \neq \emptyset\}.$$

(ii) *similarity-class-oriented generalization:*

$$L_c^\alpha(A) = \bigcup \{R_s^\alpha(x) \mid R_s^\alpha(x) \subseteq A, x \in U\},$$

$$U_c^\alpha(A) = \bigcup \{R_s^\alpha(x) \mid R_s^\alpha(x) \cap A \neq \emptyset, x \in U\}.$$

In Definition 37.3.2(i), the lower approximation consists of those elements in U whose similarity classes are contained in A . The upper approximation consists of those elements whose similarity classes overlap with A . In Definition 37.3.2(ii), the lower approximation is the union of all similarity classes that are contained in A . The upper approximation is the union of all similarity classes that overlap with A . Relationships among these approximations can be represented by:

$$L_e^\alpha(A) \subseteq L_c^\alpha(A) \subseteq A \subseteq U_e^\alpha(A) \subseteq U_c^\alpha(A).$$

The difference between lower and upper approximations is the boundary region with respect to A :

$$\text{Bnd}_e^\alpha(A) = U_e^\alpha(A) - L_e^\alpha(A), \quad \text{Bnd}_c^\alpha(A) = U_c^\alpha(A) - L_c^\alpha(A).$$

Similarly, one can define rough set approximations based on the covering $\{R_p^\alpha(x) \mid x \in U\}$.

The pair (L_e^α, U_e^α) may be interpreted as a pair of set-theoretic operators on subset of the universe. It is referred to as rough set approximation operators [37.8]. By combining with other set-theoretic operators such as \neg , \cup , and \cap , we have the following results:

$$\begin{array}{ll} \text{(re0)} & L_e^\alpha(A) = \neg U_e^\alpha(\neg A), & \text{(re5)} & L_e^\alpha(A \cup B) \supseteq L_e^\alpha(A) \cup L_e^\alpha(B), \\ & U_e^\alpha(A) = \neg L_e^\alpha(\neg A), & & U_e^\alpha(A \cup B) = U_e^\alpha(A) \cup U_e^\alpha(B), \\ \text{(re1)} & L_e^\alpha(A) \subseteq A \subseteq U_e^\alpha(A), & \text{(re6)} & A \neq \emptyset \implies U_e^0(A) = U, \\ \text{(re2)} & L_e^\alpha(\emptyset) = U_e^\alpha(\emptyset) = \emptyset, & \text{(re7)} & A \subset U \implies L_e^0(A) = \emptyset, \\ \text{(re3)} & L_e^\alpha(U) = U_e^\alpha(U) = U, & \text{(re8)} & \alpha \leq \beta \implies [U_e^\beta(A) \subseteq U_e^\alpha(A), \\ \text{(re4)} & L_e^\alpha(A \cap B) = L_e^\alpha(A) \cap L_e^\alpha(B), & & L_e^\alpha(A) \subseteq L_e^\beta(A)], \\ & U_e^\alpha(A \cap B) \subseteq U_e^\alpha(A) \cap U_e^\alpha(B), & \text{(re9)} & A \subseteq B \implies [U_e^\alpha(A) \subseteq U_e^\alpha(B), \\ & & & L_e^\alpha(A) \subseteq L_e^\alpha(B)]. \end{array}$$

(re0) shows that lower and upper approximations are dual operators with respect to set complement \neg . (re2) and (re3) provide two boundary conditions. (re4) and (re5) may be considered as weak distributive and distributive over set intersection and union, respectively. When $\alpha = 0$, (re6) and (re7) show that lower and upper approximations of a non-empty set $A \subset U$ are equal to U and \emptyset , respectively. (re8) shows that if the value of α is larger then the lower approximation is also bigger, but the upper approximation is smaller. (re9) indicates the consistency of inclusive sets.

Lower and upper approximations of Definition 37.3.2(ii), the pair (L_c^α, U_c^α) , satisfy the following properties:

$$\begin{array}{ll}
(\text{rc0}) L_c^\alpha(A) \subseteq A \subseteq U_c^\alpha(A), & (\text{rc5}) L_c^\alpha(A) = L_c^\alpha(L_c^\alpha(A)), \\
(\text{rc1}) L_c^\alpha(\emptyset) = U_c^\alpha(\emptyset) = \emptyset, & U_c^\alpha(A) = L_c^\alpha(U_c^\alpha(A)), \\
(\text{rc2}) L_c^\alpha(U) = U_c^\alpha(U) = U, & (\text{rc6}) A \neq \emptyset \implies U_c^0(A) = U, \\
(\text{rc3}) L_c^\alpha(A \cap B) \subseteq L_c^\alpha(A) \cap L_c^\alpha(B), & (\text{rc7}) A \subset U \implies L_c^0(A) = \emptyset, \\
U_c^\alpha(A \cap B) \subseteq U_c^\alpha(A) \cap U_c^\alpha(B), & (\text{rc8}) \alpha \leq \beta \implies [U_c^\beta(A) \subseteq U_c^\alpha(A), \\
(\text{rc4}) L_c^\alpha(A \cup B) \supseteq L_c^\alpha(A) \cup L_c^\alpha(B), & L_c^\alpha(A) \subseteq L_c^\beta(A)], \\
U_c^\alpha(A \cup B) = U_c^\alpha(A) \cup U_c^\alpha(B), & (\text{rc9}) A \subseteq B \implies [U_c^\alpha(A) \subseteq U_c^\alpha(B), \\
& L_c^\alpha(A) \subseteq L_c^\alpha(B)].
\end{array}$$

It should be pointed out that they are not a pair of dual operators. Property (rc5) indicates that the results of iterative operations of both lower and upper approximation operators are the same a single application.

37.4 Conclusions

In this paper, we introduce the notion of weak fuzzy similarity relations. Two examples of such relations, conditional probability relations and fuzzy conditional probability relations, are suggested for the construction and interpreting coverings of the universe. Based on such coverings, we generalize the standard rough set approximations. Two pairs of lower and upper approximation operators are suggested and studied. Their properties are examined.

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38. On Mining Ordering Rules

Y.Y. Yao and Ying Sai

Department of Computer Science, University of Regina
Regina, Saskatchewan, Canada S4S 0A2
yyao@cs.uregina.ca

Many real world problems deal with ordering of objects instead of classifying objects, although majority of research in machine learning and data mining has been focused on the latter. In this paper, we formulate the problem of mining ordering rules as finding association between orderings of attribute values and the overall ordering of objects. An example of ordering rules may state that “if the value of an object x on an attribute a is ordered ahead of the value of another object y on the same attribute, then x is ordered ahead of y ”. For mining ordering rules, the notion of information tables is generalized to ordered information tables by adding order relations on attribute values. Such a table can be transformed into a binary information table, on which any standard data mining algorithm can be used.

38.1 Introduction

In real world situations, we may be faced with many problems that are not simply classification [38.1, 38.4]. One such type of problems is the ordering of objects. Two familiar examples of ordering problems are the ranking of universities and the ranking of the consumer products produced by different manufactures. In both examples, we have a set of attributes that are used to describe the objects under consideration, and an overall ranking of objects. Consider the example of ranking consumer products. Attributes may be the price of the products, warranty of the products, and other information. The values of a particular attribute, say the price, naturally induce an ordering of objects. The overall ranking of products may be produced by the market shares of different manufactures. The orderings of objects by attribute values may not necessarily be the same as the overall ordering of objects.

The problem of mining ordering rules can be stated as follows. There is a set of objects described by a set of attributes. There is an ordering on values of each attribute, and there is also an overall ordering of objects. The overall ordering may be given by experts or obtained from other information, either dependent or independent of the orderings of objects according to their attribute values. We are interested in mining the association between the overall ordering and the individual orderings induced by different attributes. More specifically, we want to derive ordering rules exemplified by the statement that “if the value of an object x on an attribute a is ordered ahead of the value of another object y on the same attribute, then x is ordered ahead of y ”. In this setting, a number of important issues arise. It would be interesting to

know which attributes play more important roles in determining the overall ordering, and which attributes do not contribute at all to the overall ordering. It would also be useful to know which subset of attributes would be sufficient to determine the overall ordering. The dependency information of attributes may also be valuable.

For mining ordering rules, we first introduce the notion of ordered information tables as a generalization of information tables. We then transform an ordered information table into a binary information table, on which any standard data mining and machine learning algorithms can be applied. Typically, an ordering rule may not be exact. In order to capture the uncertainty associated with ordering rules, two quantitative measures are used. They are the accuracy and the coverage of the rules [38.5, 38.7]. The former deals with the correctness of the rules, and the latter represents the extent to which the rule covers the positive instances.

Ordered information tables are related to ordinal information systems proposed and studied by Iwinski [38.3]. Mining ordering rules has been studied by Greco, Matarazzo and Slowinski [38.2]. Based on these studies, the main objective of the present paper is to precisely define and formulate the problem of mining ordering rules.

38.2 Ordered Information Tables

Formally, an ordered information table is defined by:

$$OIT = (U, At, \{V_a \mid a \in At\}, \{I_a \mid a \in At\}, \{\succ_a \mid a \in At\}),$$

where

- U is a finite nonempty set of objects,
- At is a finite nonempty set of attributes,
- V_a is a nonempty set of values for $a \in At$,
- $I_a : U \rightarrow V_a$ is an information function,
- $\succ_a \subseteq V_a \times V_a$ is an order relation on V_a .

Each information function I_a is a total function that maps an object of U to exactly one value in V_a . An ordered information table can be conveniently given in a tabular form, the rows correspond to objects of the universe, the columns correspond to a set of attributes, and each cell is the value of an object with respect to an attribute. The order relations can be interpreted as additional semantics information about the table.

An order relation should satisfy certain conditions. We consider the following two properties [38.6]:

$$\begin{aligned} \text{Asymmetry} &: x \succ y \implies \neg(y \succ x), \\ \text{Negative transitivity} &: [\neg(x \succ y), \neg(y \succ z)] \implies \neg(x \succ z). \end{aligned}$$

An order relation satisfying these properties is called a weak order. An important implication of a weak order is that the following relation,

$$x \sim y \iff [\neg(x \succ y), \neg(y \succ x)], \quad (38.1)$$

is an equivalence relation. For two elements, if $x \sim y$ we say x and y are indiscernible by \succ . The equivalence relation \sim induces a partition U/\sim on U , and an order relation on U/\sim can be defined by:

$$[x]_{\sim} \succ^* [y]_{\sim} \iff x \succ y, \quad (38.2)$$

where $[x]_{\sim}$ is the equivalence class containing x . Moreover, \succ^* is a linear order [38.6]. Any two distinct equivalence classes of U/\sim can be compared. It is therefore possible to arrange the elements into levels, with each level consisting of indiscernible elements defined by \succ . For a weak order, $\neg(x \succ y)$ can be written as $y \succeq x$ or $x \preceq y$, which means $y \succ x$ or $y \sim x$. For any two elements x and y , we have either $x \succ y$ or $y \succeq x$, but not both.

We assume that all order relations are weak orders. An order relation on values of an attribute a naturally induces an ordering of objects:

$$x \succ_{\{a\}} y \iff I_a(x) \succ_a I_a(y), \quad (38.3)$$

where $\succ_{\{a\}}$ denotes an order relation on U induced by the attribute a . An object x is ranked ahead of another object y if and only if the value of x on the attribute a is ranked ahead of the value of y on a . The relation $\succ_{\{a\}}$ has exactly the same properties as that of \succ_a . For simplicity, we also assume that there is a special attribute, called decision attribute. The ordering of objects by the decision attribute is denoted by \succ_o and is called the overall ordering of objects. For a subset of attributes $A \subseteq At$, we define:

$$\begin{aligned} x \succ_A y &\iff \forall a \in A [I_a(x) \succ_a I_a(y)] \\ &\iff \bigwedge_{a \in A} I_a(x) \succ_a I_a(y) \iff \bigcap_{a \in A} \succ_{\{a\}}. \end{aligned} \quad (38.4)$$

That is, x is ranked ahead of y if and only if x is ranked ahead of y according to all attributes in A .

38.3 Mining Ordering Rules

With an ordered information table, we are interested in find ordering rules of the form $\phi \Rightarrow \psi$, where ϕ and ψ are expressions regarding ordering of objects based on certain attributes. For an attribute a , we can construct two atomic expressions (a, \succ) and (a, \preceq) . The former indicates that objects are ordered based on \succ and the latter indicates that objects are ordered based on \preceq . A set of expressions can be obtained from atomic expressions through the application of logic connectives \neg , \wedge and \vee . Consider an ordering rule,

$$(a, \succ) \wedge (b, \preceq) \Rightarrow (c, \succ).$$

It can be re-expressed as,

$$x \succ_{\{a\}} y \wedge x \preceq_{\{b\}} y \Rightarrow x \succ_{\{c\}} y,$$

and paraphrased as follows. For two arbitrary objects x and y , if x is ranked ahead of y by attribute a , and at the same time, x is not ranked ahead of y by attribute b , then x is ranked ahead of y by attribute c .

The meanings of expressions are defined by:

$$(m1). \quad m((a, \succ)) = \{(x, y) \in U \times U \mid x \succ_{\{a\}} y\},$$

$$(m2). \quad m((a, \preceq)) = \{(x, y) \in U \times U \mid x \preceq_{\{a\}} y\},$$

$$(m3). \quad m(\neg\phi) = -m(\phi),$$

$$(m4). \quad m(\phi \wedge \psi) = m(\phi) \cap m(\psi),$$

$$(m5). \quad m(\phi \vee \psi) = m(\phi) \cup m(\psi).$$

A pair $(x, y) \in m(\phi)$ is said to satisfy the expression ϕ . In terms of the meanings of expressions, we can have many conditional probabilistic interpretations for ordering rules [38.7]. We choose to use two measures called accuracy and coverage, which are defined by [38.5]:

$$accuracy(\phi \Rightarrow \psi) = \frac{|m(\phi \wedge \psi)|}{|m(\phi)|}, \quad coverage(\phi \Rightarrow \psi) = \frac{|m(\phi \wedge \psi)|}{|m(\psi)|}, \quad (38.5)$$

where $|\cdot|$ denotes the cardinality of a set. While the accuracy reflects the correctness of the rule, the coverage reflects the applicability of the rule. If $accuracy(\phi \Rightarrow \psi) = 1$, the orderings by ϕ would determine the orderings by ψ . We thus have a strong association between the two orderings. A smaller value of *accuracy* indicates a weaker association. An ordering rule with higher coverage suggests that ordering of more pairs of objects can be derived from the rule. The accuracy and coverage are not independent of each other, as both are related to the quantity $|m(\phi \wedge \psi)|$. It is desirable for a rule to be accurate as well as to have a high degree of coverage. In general, one may observe a trade-off between accuracy and coverage. A rule with higher coverage may have a lower accuracy, while a rule with higher accuracy may have a lower coverage.

From an ordered information table, we can construct a binary information table. We consider all pairs of objects which are the Cartesian product $U \times U$. The information function is defined by:

$$I_a(x, y) = \begin{cases} 1, & x \succ_{\{a\}} y, \\ 0, & x \preceq_{\{a\}} y. \end{cases} \quad (38.6)$$

The value 1 corresponds to the atomic expression (a, \succ) and the value 0 corresponds to the atomic expression (a, \preceq) . Statements in an ordered information

table can be translated into equivalent statements in the binary information table, and vice versa. For example, a pair (x, y) satisfies the expression (a, \succ) if and only if it satisfies an expression $I_a(x, y) = 1$. In other words, the statement $x \succ_{\{a\}} y$ can be translated into an equivalent statement $I_a(x, y) = 1$. In the translation process, we will not consider object pairs of the form (x, x) , as we are not interested in them.

The interpretation of an ordered information table and the translation to a binary information table are crucial for mining ordering rules. Once we obtain the binary information table, any standard machine learning and data mining algorithms can be used to mine ordering rules. One may also use other types of translation methods. For example, we may consider two strict order relations \succ and \prec , instead of \succ and \preceq . Alternatively, one may translate an ordered information table into a three-valued information table, corresponding to \succ , \prec , and \sim . It is important to realized that the framework presented in this paper can be easily applied with very simple modification.

38.4 Conclusion

Ordering of objects is a fundamental issue in human decision making and may play a significant role in the design of intelligent information systems. This problem is considered from the perspective of data mining. The commonly used attribute value approaches are extended by introducing order relations on attribute values. Mining ordering rules is formulated as the process of finding associations between orderings on attribute values and the overall ordering of objects. These ordering rules tell us, or explain, how objects should be ranked according to orderings on their attribute values.

Our main contribution is the formulation of the problem of mining ordering rules, and the translation of the problem to existing data mining problems. Consequently, one can directly apply any existing data mining algorithms for mining ordering rules. Depending on the specific problem, one may use different translation methods.

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39. Non-additive Measures by Interval Probability Functions

Hideo Tanaka¹, Kazutomi Sugihara², and Yutaka Maeda³

¹ Graduate School of Management and Information Science, Toyohashi Sozo College

20-1 Matsushita, Ushikawacho, 440-8511, Toyohashi, JAPAN

tanakah@sozo.ac.jp, hctanaka@kcn.ne.jp

² Course of Applied Physics, Graduate School of Engineering Osaka University

Yamadaoka 2-1, Suita, Osaka, 565-0871, JAPAN

sugihara@ap.eng.osaka-u.ac.jp

³ Department of Industrial Engineering, College of Engineering Osaka Prefecture University

Gakuencho 1-1, Sakai, Osaka, 590-8531, JAPAN

maeda@ie.osakafu-u.ac.jp

Probability measures are well-defined ones that satisfy additivity. However, it is slightly tight because of its condition of additivity. Fuzzy measures that do not satisfy additivity have been proposed as the substitute measures. The only belief function involves a density function among them. In this paper, we propose two density functions by extending values of probability functions to interval values, which do not satisfy additivity. According to the definition of interval probability functions, lower and upper probabilities are defined, respectively. A combination rule and a conditional probability can be defined well. The properties of the proposed measure are clarified.

39.1 Introduction

Probability theory is well defined for representing uncertainty under the assumption that a probability distribution is always determined from the given information. However this assumption is not satisfied with real situations in many problems. In the case where we can not determine only one probability distribution, it is appropriate that we speculate a set of probability distributions from an uncertain information given by estimators. There are many articles [39.2] [39.4] [39.6] [39.7] [39.8] [39.9] where an uncertain information has been handled by a set of distributions. These measures in the above papers do not satisfy additivity that is an important role in the conventional probabilities. Non-additive measures can be said to be a kind of fuzzy measures [39.12]. Fuzzy measures have been dealt with distribution functions, but density functions are not discussed yet in non-additive measures except for belief functions [39.10]. Belief functions and random sets are different basically from viewpoint of underlying theories. Nevertheless there is the method by which a belief function including the given random set can be obtained [39.11].

In this paper, we propose two probability functions by extending values of probabilities to interval values, which do not satisfy additivity. This idea is similar to the concept of intuitionistic fuzzy sets [39.1] that can be said to be fuzzy rough sets [39.5]. According to the definition of interval probabilities, lower and upper probabilities are defined, respectively. A combination rule and a conditional probability can be defined well. The properties of the proposed measure are clarified.

39.2 Interval Probability Functions

In this paper, interval probability functions denoted as IPF are proposed by two density functions. IPF is an extension of probability values to interval probability values.

Definition 1. The set of two functions denoted as (h_*, h^*) is called IPF if and only if

- (a) $\forall x' \in X, h^*(x') \geq h_*(x') \geq 0$
- (b) $\sum_{x \in X} h_*(x) + (h^*(x') - h_*(x')) \leq 1$
- (c) $\sum_{x \in X} h^*(x) - (h^*(x') - h_*(x')) \geq 1.$

The above (b) and (c) can be rewritten as

- (b') $\sum_{x \in X} h_*(x) + \max_{x'} (h^*(x') - h_*(x')) \leq 1$
- (c') $\sum_{x \in X} h^*(x) - \max_{x'} (h^*(x') - h_*(x')) \geq 1.$

Theorem 1. There exists a probability function $h'(x)$ that satisfies

$$h_*(x) \leq h'(x) \leq h^*(x), \quad \sum_{x \in X} h'(x) = 1. \quad (39.1)$$

Two distribution functions can be defined by IPF as follows. Let the lower and upper functions be denoted as $LB(\cdot)$ and $UB(\cdot)$ respectively.

Definition 2. $LB(\cdot)$ and $UB(\cdot)$ can be defined as

$$LB(A) = \min_{h'} \left(\sum_{x \in A} h'(x) \right) \quad (39.2)$$

$$UB(A) = \max_{h'} \left(\sum_{x \in A} h'(x) \right) \quad (39.3)$$

where $h_*(x) \leq h'(x) \leq h^*(x)$.

From Definition 2, the following theorem holds.

Theorem 2. For $\forall A \subseteq X$, we have

$$LB(A) = \sum_{x \in A} h_*(x) \vee \left(1 - \sum_{x \in \bar{A}} h^*(x) \right) \quad (39.4)$$

$$UB(A) = \sum_{x \in A} h^*(x) \vee \left(1 - \sum_{x \in \bar{A}} h_*(x) \right). \quad (39.5)$$

Theorem 3. The functions LB and UB are superadditive and subadditive, respectively.

The proof is omitted because of the limited space. It follows clearly from Theorem 2 that the following dual relation holds.

$$LB(A) = 1 - UB(\bar{A}). \quad (39.6)$$

Let us consider the properties of IPF.

Property 1. There is only one element such that its value of IPF is positive if and only if

$$\forall x \in (X - \{x_1\}), h^*(x) = 0, h_*(x_1) = h^*(x_1) = 1. \quad (39.7)$$

Property 2. There are only two elements such that these values of IPF are positive if and only if

$$\begin{aligned} \forall x \in (X - \{x_1, x_2\}), h^*(x) = 0, \\ h_*(x_1) + h^*(x_2) = h^*(x_1) + h_*(x_2) = 1. \end{aligned} \quad (39.8)$$

Property 3. There is no element such that an interval value is positive ($h^*(x) - h_*(x) > 0$) if and only if it is a probability function.

Property 4. There is no case such that only one element has an interval value.

Property 5. There are only two elements such that interval values are positive ($h^*(x) - h_*(x) > 0$) if and only if

$$\begin{aligned} \forall x \in (X - \{x_1, x_2\}), h_*(x) = h^*(x), \\ h_*(x_1) + h^*(x_2) = h^*(x_1) + h_*(x_2) \\ = 1 - \sum_{x \in (X - \{x_1, x_2\})} h_*(x) = 1 - \sum_{x \in (X - \{x_1, x_2\})} h^*(x). \end{aligned} \quad (39.9)$$

These properties can be easily proved from the definition of IPF.

39.3 Combination and Conditional Rules for IPF

Let us consider a combination rule to combine two interval probability functions into one probability function.

Definition 3. Let two interval density functions be denoted as $(h_{1*}(x), h_1^*(x))$ and $(h_{2*}(x), h_2^*(x))$. Then the combination rule is defined as

$$h_{12*} = h_{1*} \wedge h_{2*} \tag{39.10}$$

$$h_{12}^* = h_1^* \vee h_2^* \tag{39.11}$$

It is verified that the combined function $(h_{12*}(x), h_{12}^*(x))$ is also IPF. This combination rule is proposed from viewpoint of possibility, although Dempster's combination rule on belief functions [39.10] is defined from viewpoint of necessity. In belief measures, the combination rule entails the conditional rule, but in IPF the conditional rule is defined independently as follows.

Definition 4. The lower and upper functions conditioned by $B \subset X$ are defined as

$$LB(A|B) = \frac{LB(AB)}{LB(AB) + UB(B - AB)} \tag{39.12}$$

$$UB(A|B) = \frac{UB(AB)}{UB(AB) + LB(B - AB)} \tag{39.13}$$

where $UB(B) \neq 0$ and for $\frac{0}{0}$ we set $LB(A|B) = 1$ and $UB(A|B) = 0$. From the dual relation, we can see easily that $LB(A|X) = LB(A)$ and $UB(A|X) = UB(A)$. Using Definition 4, we can obtain two density functions as follows:

$$h_{1*}(x) = LB(\{x\}|B) \tag{39.14}$$

$$h_1^*(x) = UB(\{x\}|B) \tag{39.15}$$

where $h_{1*}(x) = h_1^* = 0$ for $x \in \bar{B}$. These two functions can be rewritten as follows:

$$h_{1*}(x) = LB(\{x\}|B) = \frac{h_{0*}(x)}{h_{0*}(x) + \sum_{x' \in B - \{x\}} h_0^*(x')} \vee \frac{h_{0*}(x)}{h_{0*}(x) + \sum_{x' \in \bar{B}} h_{0*}(x')} \tag{39.16}$$

$$h_1^*(x) = UB(\{x\}|B) = \frac{h_0^*(x)}{h_0^*(x) + \sum_{x' \in B - \{x\}} h_0^*(x')} \vee \frac{h_0^*(x)}{h_0^*(x) + \sum_{x' \in \bar{B}} h_{0*}(x')} \tag{39.17}$$

where (h_{0*}, h_0^*) is a given IPF.

Theorem 4. Two probability functions (h_{1*}, h_1^*) obtained by the above equations satisfy the definition of IPF.

Here the proof of Theorem 4 is skipped. Conditional probability functions are IPF. The lower and upper functions based on IPF (h_{1*}, h_1^*) defined the above are denoted as $LB_1(AB)$ and $UB_1(AB)$ respectively. Then, we have the following relation.

$$LB_1(AB) \leq LB_1(A|B) \leq UB_1(A|B) \leq UB_1(AB). \quad (39.18)$$

This means that the lower and upper functions obtained from probability functions induced by the conditional rule are wider than ones directly calculated by the conditional rule are.

39.4 Concluding Remarks

IPF is useful to obtain interval weights in AHP [39.12]. The definition of IPF can be regarded as an extension of normalization of conventional probabilities. This research work is a first step for interval probability functions, but there are many problems with respect to IPF for future study.

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40. Susceptibility to Consensus of Conflict Profiles

Ngoc Thanh Nguyen

Department of Information Systems,
Wrocław University of Technology, Poland
thanh@pwr.wroc.pl

By a conflict profile we understand a set of data versions representing different opinions on some matter, generated by agents functioning in some sites of a distributed system. In purpose to solve this conflict the management system should determine a proper version of data for this matter. The final data version is called a consensus of given conflict profile. The main subject of this paper consists of consideration of existence and reasonableness of potential consensus. In other words, we consider problems related to consensus susceptibility of conflict profiles.

40.1 Introduction

Consensus theory [1],[2] is useful in conflict solving. The resource of conflicts in distributed systems arises as the result of the autonomy feature of systems sites [3]. The simplest conflict takes place when two bodies have different opinions on the same subject. In work [5] Pawlak specifies the following elements of an one-value conflict: a set of agents, a set of issues, and a set of opinions of these agents on these issues. The agents and the issues are related with one another in some social or political context. Information tables [6] should be useful for representing this kind of conflicts. In this paper we define a consensus system which represents multi-value conflicts. In this system we distinguish conflict profiles containing versions of data which are generated by different participants of a conflict and refer to a conflict subject. Next consensus for conflict profiles is defined and two problems of susceptibility to consensus for profiles are considered.

40.2 Conflict Profiles

For representing potential conflicts we use a finite set \mathbf{A} of attributes and a set V of attribute elementary values, where $\mathbf{V} = \bigcup_{a \in \mathbf{A}} V_a$ (V_a is the domain of attribute a). Let $\prod(V_a)$ denote the set of subsets of set V_a and $\prod(V_B) = \bigcup_{b \in B} \prod(V_b)$. Let $B \subseteq \mathbf{A}$, a tuple r_B of type B is a function $r_B : B \rightarrow \prod(V_B)$ where $(\forall b \in B)(r_b \subseteq V_b)$. A tuple is elementary if all attribute values are empty sets or 1-element sets. Empty tuple is denoted by symbol ϕ . The set of all tuples of type B is denoted by $TYP(B)$ and

the set all elementary tuples of type B is denoted by $E - TYP(B)$. We assume that some real world is commonly considered by agents which are placed in sites of a distributed system. The interest of the agents consists of events which occur (or have to occur) in the world. The task of the agents is based on determining the values of event attributes (an event is described by an elementary tuple of some type). The consensus system is defined as a triple $Consensus_Sys = (\mathbf{A}, \mathbf{X}, \mathbf{P})$, where: \mathbf{A} is a finite set of attributes, which includes a special attribute $Agent$; values of attribute a are subsets of V_a ; values of attribute $Agent$ are 1-element sets, which identify the agents; $\mathbf{X} = \{\prod(V_a) : a \in \mathbf{A}\}$ is a finite set of consensus carriers; \mathbf{P} is a finite set of relations on carriers from \mathbf{X} , each relation is of some type A (for $A \subseteq \mathbf{A}$ and $Agent \in A$). Relations belonging to set P are classified in such way that each of them includes relations representing similar events. For identifying relations belonging to given group the symbols "+" and "-" should be used as the upper index. If P is the name of a group, then relation P^+ is called a positive relation (contains positive knowledge) and P^- is the negative relation (contains negative knowledge). The structures of the consensus carriers is defined as a distance function between tuples of the same type. This function can be defined on the basis of one of distance functions δ^P and ρ^P between sets of elementary values [4].

Definition 40.2.1. For 2 tuples r and r' of type A the distance function φ assigns a number $\partial(r, r') = \frac{1}{card(A)} \sum_{a \in A} \varphi(r_a, r'_a)$ where $\varphi \in \{\rho^P, \delta^P\}$.

Consensus is considered within a consensus situation, defined as follows:

Definition 40.2.2. A consensus situation is a pair $\{\{P^+, P^-\}, A \rightarrow B\}$ where $A, B \subseteq \mathbf{A}$, $A \cap B = \emptyset$ and for every tuple $r \in P^+ \cup P^-$ there should be held $r_A \neq \phi$.

The first element of a consensus situation includes the domain from which consensus should be chosen, and the second element presents the subjects of consensus (i.e. set $Subject(s) \subseteq E - TYP(A)$) and the content of consensus, such that for a subject e there should be assigned only one tuple of type B . For each subject $e \in 2$ conflict profiles $profile(e)^+, profile(e)^- \subseteq TYP(A \cup B)$ should be determined.

Definition 40.2.3. Consensus on subject $e \in Subject(s)$ is a set of 2 tuples $\{C(s, e)^+, C(s, e)^-\}$ of type $A \cup B$ which fulfill the following conditions:

- a) $C(s, e)_A^+ = C(s, e)_A^- = e$,
- b) $\sum_{r \in profile(e)^+} \partial(r_B, C(s, e)_B^+)$ and $\sum_{r \in profile(e)^-} \partial(r_B, C(s, e)_B^-)$ are minimal,
- c) $C(s, e)_B^+ \cap C(s, e)_B^- = \phi$.

Any tuples $C(s, e)^+$ and $C(s, e)^-$ satisfying conditions a)-b) are called consensuses of profiles $profile(e)^+$ and $profile(e)^-$ respectively.

40.3 Susceptibility to Consensus

In this section we investigate two problems referring to susceptibility to consensus for conflict profiles. For given situation $s = \langle \{P^+, P^-\}, A \rightarrow B \rangle$ there may exist two following problems:

1. For given subject $e \in \text{Subject}(s)$ when any tuples $C(s, e)^+, C(s, e)^- \in \text{Typ}(A \cup B)$ satisfying conditions a)-b) specified in Definition 4 (that is being consensus of profiles $\text{profile}(e)^+$ and $\text{profile}(e)^-$ respectively) may create a consensus, that means when the last condition $C(s, e)_B^+ \cap C(s, e)_B^- = \phi$ may be fulfilled?
2. If consensus of a profile exists, is it good enough for this profile?

For explaining the first problem we give the following example:

Example 40.3.1. In the meteorological system [3] let us consider the following situation $s = \langle \text{Rain}^+, \text{Rain}^-, \text{Region} \rightarrow \text{Time} \rangle$ where determined from relations Rain^+ and Rain^- profiles $\text{profile}(e)^+$ and $\text{profile}(e)^-$ for $e = \langle \text{Region} : r_1 \rangle$ have the following form:

$\text{profile}(e)^+$			$\text{profile}(e)^-$		
Agent	Region	Time	Agent	Region	Time
a_1	r_1	3a.m.-5a.m.	a_1	r_1	2a.m.-6a.m.
a_2	r_1	4a.m.-6a.m.	a_2	r_1	4a.m.-5a.m.
a_3	r_1	4a.m.-5a.m.	a_3	r_1	6a.m.-8a.m.

Using distance function ρ^P we obtain the following tuples $C(s, e)^+$ and $C(s, e)^-$ of type $\{\text{Region}, \text{Time}\}$, which fulfill conditions a)-b) of Definition 4: $C(s, e)^+ = \langle \text{Region} : r_1, \text{Time} : 4a.m. - 5a.m. \rangle$, $C(s, e)^- = \langle \text{Region} : r_1, \text{Time} : 4a.m. - 6a.m. \rangle$. Let us note that these tuples do not satisfy the condition c) of Definition 4, because $C(s, e)_{\{\text{Time}\}}^+ \cap C(s, e)_{\{\text{Time}\}}^- \neq \phi$, thus they can not create a consensus for subject e .

The second problem is the main subject of this section. It often happens that for a given conflict it is possible to determine consensus. The question is: is the chosen consensus good enough and can it be acceptable as the solution of given conflict situation? In other words, is the conflict situation susceptible to (good) consensus? We will consider the susceptibility to consensus for conflict profiles. Before defining the notion of susceptibility to consensus below we present an example.

Example 40.3.2. Let a space (U, ∂) be defined as follows: $U = \{a, b\}$ where a and b are tuples of some type, and distance function ∂ is given as: For $x, y \in U$ $\partial(x, y) = 0$ if $x = y$ and $\partial(x, y) = 1$ otherwise. Let X be a profile being a set with repetitions, where $X = \{50 \cdot a, 50 \cdot b\}$. Assume that X represents the result of some voting, in which 100 agents take part, each of them gives one vote (for a or b). There are 50 votes for a and 50 votes for b . It is easy to note that for profile X the consensus should be equal to a or b , but it intuitively seems that none of them is a good consensus, because there is lack of a compromise in this conflict situation. Let us consider now another

profile $X' = \{50 \cdot a, 51 \cdot b\}$. For this profile the only consensus should be b and it seems to be a good consensus, that means this profile is susceptible to consensus.

The above example shows that although consensus may always be chosen for a conflict profile, it does not have to be a good one. We define below the notion of profile' susceptibility to consensus.

Let $X \in \{profile(e)^+, profile(e)^-\}$ for $e \in Subject(s)$, $card(X) = n$ and

$$\hat{\partial}(X) = \frac{\sum_{x,y \in X} \hat{\partial}(x_B, y_B)}{n(n+1)}, \quad \hat{\partial}(x, X) = \frac{\sum_{y \in X} \partial(x_B, y_B)}{n},$$

$$\hat{\partial}_{min}(X) = \min_{x \in TYP(B)} \hat{\partial}(x, X), \quad \hat{\partial}_{max}(X) = \max_{x \in TYP(B)} \hat{\partial}(x, X).$$

Profile X is regular if for each $x, y \in X$ equality $\hat{\partial}(x, X) = \hat{\partial}(y, X)$ follows, profile X is irregular if there exist two its elements x and y such that $\hat{\partial}(x, X) \neq \hat{\partial}(y, X)$.

Definition 40.3.1. Profile X is susceptible to consensus iff $\hat{\partial}(X) \geq \hat{\partial}_{min}(X)$.

For the profiles defined in Example 2 we have $\hat{\partial}(X) = \frac{2 \cdot 50 \cdot 50}{100 \cdot 101} = \frac{50}{101} < \hat{\partial}_{min}(X) = \frac{50}{100}$. Thus profile X should not be susceptible to consensus. It is agreed with intuition because neither a nor b should be a "good consensus" for this profile. However $\hat{\partial}(X') = \frac{2 \cdot 50 \cdot 51}{101 \cdot 102} = \frac{50}{101} = \hat{\partial}_{min}(X')$. Thus profile X' should be susceptible to consensus. According to intuition b should be a "good" consensus because it dominates a in profile X' . Below we present some properties of consensus susceptibility.

Theorem 40.3.1. If X is a regular profile and $card(X) > 1$ then X is not susceptible to consensus.

Profile X in Example 2 is a regular one, therefore it is not susceptible to consensus. Let symbol $\dot{\cup}$ represent the sum operation on sets with repetitions, we have the following:

Theorem 40.3.2. Let X and X' be such conflict profiles that $card(X) > 1$, $X' = X \dot{\cup} \{x\}$ for some $x \in X$ and X is regular, then profile X' should be susceptible to consensus.

Notice that profiles X and X' in Example 2 satisfy the conditions in Theorem 2, so, as stated, X' should be susceptible to consensus. Theorem 2 shows also that if profile X is regular then its extending by some element of itself gives a profile which should be susceptible to consensus. The practical sense of this theorem is that if in given conflict situation none of votes dominates and in the second voting extended by one voter who gives his vote for one of the previous ones, then the new profile should be susceptible to consensus.

For given conflict profile X , where $X \in \{profile(e)^+, profile(e)^-\}$, which elements are tuples of type B let $Occ(X, x)$ for $x \in E - TYP(B)$ denote the number of occurrences of elementary tuple x in tuples belonging to X . Let $card(X) = n$ and

$$\begin{aligned}
M &= \sum_{y \in E - TYP(B)} 2Occ(X, y)(n - Occ(X, y))p_y; \\
X_1 &= \{x \in E - TYP(B) : Occ(X, x) = \frac{n}{2}\}; \quad M_1 = \sum_{y \in X_1} \frac{n}{2}p_y; \\
X_2 &= \{x \in E - TYP(B) : 0 < Occ(X, x) < \frac{n}{2}\}; \quad M_2 = \sum_{y \in X_2} Occ(X, y)p_y; \\
X_3 &= \{x \in E - TYP(B) : \frac{n}{2} < Occ(X, x) < n\}; \quad M_3 = \sum_{y \in X_3} (n - Occ(X, y))p_y
\end{aligned}$$

for $p_y = 1$ if function ρ^P is used and $p_y = d(y)$ if function δ^P is used, where $d(y)$ is the cost of adding (moving) elementary tuple to (from) profile X .

Theorem 40.3.3. *If distance functions δ^P and ρ^P are used for determining consensus then the following dependencies are true:*

- a) *If n is an odd number then profile X is always susceptible to consensus,*
- b) *If n is an even number then profile X is susceptible to consensus if and only if $M_1 + M_2 + M_3 \leq M/(n + 1)$.*

Theorem 3 allows to state if a given profile is susceptible to consensus or not without determining the consensus. It has been pointed out that if the number of agents taking part in the conflict is odd then the profile is always susceptible to consensus, and if this number is even then some condition must be satisfied.

40.4 Conclusions

In this paper some results of investigation on the problems related to specifying conditions which allow to find out if a conflict profile is susceptible to consensus, are presented. The future work should concern the first problem specified in Section 3. Its solution should allow us to find out if a conflict situation is consensus-oriented or not. Another interesting aspect of the consensus model is introducing probabilistic elements to conflict content to extend the possibilities for agents for their opinion representation. In this case the tools which enable to join rough set theory and probabilistic calculus [7] should be useful.

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41. Analysis of Image Sequences for the Unmanned Aerial Vehicle*

Hung Son Nguyen, Andrzej Skowron, and Marcin S. Szczuka

Institute of Mathematics, Warsaw University
Banacha 2, 02-097, Warsaw, Poland
{son,skowron,szczuka}@mimuw.edu.pl

A method for extracting relevant information from image sequence data is presented. The image sequences, being output of video system of the Unmanned Aerial Vehicle, are analysed with use of EM-clustering techniques and Rough Set based methods. The possibilities of construction of an automated system for recognition/identification of cars on the road, on the basis of colour-related data are discussed.

41.1 Introduction

The issue of constructing and controlling an autonomous Unmanned Aerial Vehicle (UAV) is a multi-fold one. The idea of constructing such a vehicle (helicopter) for the purposes of traffic control drives the WITAS project (see [41.8]). Apart of difficulties in construction of proper hardware the problem of establishing software is a challenging one. The UAV is supposed to recognise the road situation underneath on the basis of sensor readings and make the decision about acts that are to be performed. The issue of constructing adaptive, intelligent and versatile system for identification of situation was addressed in [41.5]. In the paper we focus on one of the subtasks necessary for the entire system to work – the problem of discerning between objects that are visible to the UAV.

The most crucial information for UAV is provided by its video systems. We have to be able to provide UAV control system with information about car colors and so on. Such information may allow for making the identification that is core for operations performed by UAV, such as tracking a single vehicle over some time.

In the paper we address only a part of issues that have to be resolved. The particular task we are dealing with is identification of techniques that may be used for the purpose of discerning and/or classifying objects from image sequence data. Given a series of images gathered by UAV's video system we have to extract the valuable information about cars present in the image. The key is to have compact set of features that at the same time are robust the image data may be heavily distorted. The unwanted effects coming from changes in UAV's position, lighting conditions, scaling, rotation and weather conditions have to be compensated.

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41.2 Data Description

At the current stage we are dealing with two sequences of images consisting of 100 frames each. They represent two situations on the road, each about 4 second long. Every frame is a 24 bit .tiff image with resolution 726×512 pixels. The image sequences have been manually interpreted. Altogether 18 objects representing cars on the road have been identified. The object instance (colour blob) is represented with 30 attributes: number (identifier) assigned to an object, two numerical attributes representing X and Y coordinates (within an image) of the center of colour blob (object) and 27 attributes representing coordinates in the RGB colour space for 9 pixels being a 3×3 matrix surrounding the center of colour blob. For each of 18 identified object we have 100 instances, one for each image in sequence (1800 samples in total).

41.3 The Task

The overall problem of situation identification on the basis of image (and possibly some other) data is very compound. In the first stage, described in this paper we would like to find the answers to the following questions:

1. Is the existing amount of information (27 colour-related attributes) sufficient for construction of classification support system that is able to distinguish between 18 pre-identified objects?
2. Is it possible to transform the existing 27 dimensional attribute space to the form better supporting car colour classification tasks?
3. Is it possible to learn the basic concepts allowing for establishment of prototypes rules of classification provided we have part of the sequence, say first 50 images, and then classify objects for the rest of sequence properly?

41.4 The Method

Initially, an attempt to perform car (colour blob) dissemination and/or classification with use of typical methods from the Rough Set armory (see [41.4]) have been made. Unfortunately, it turned out that the data is too vague and distorted for the typical tools like RSES ([41.7]) or Rosetta ([41.6]).

We came to the conclusion that some method for extraction of more relevant features from the raw data is needed. Therefore we turned our attention at unsupervised learning methods that allow for identification of characteristic features of objects in the corpus. The main intention is to eliminate unwanted effects caused by changes in object RGB colours as the object (car) moves between zones of different light. The particular approach we apply uses clustering and simple time series analysis.

First, we perform clustering treating all 1800 measurements as points in 27 dimensional space (9 points \times 3 RGB coordinates). To do the clustering we utilise Expectation Maximisation (EM) method. EM-clustering is an iterative, unsupervised clustering method aimed at establishment of possibly small number of not intersecting clusters constructed with assumptions about normal distribution of objects. For details about EM clustering see [41.1] and [41.3].

After the clustering have been found we recall the information about sequential character of our data. Namely, we analyse the sequences of cluster assignments for each of 18 cars. Going frame-by-frame we check to which clusters the object belong in scope of this frame. In this way for each of 18 cars we get a vector of 100 cluster assignments. Such vectors may be compared and on the basis of differences between them we may discern one car from the others.

41.5 Results

The clustering was applied to the entire data. As a result of several experiments we got 15 to 18 clusters on the average. For all objects the assignment to cluster was very characteristic. In most cases it was possible to distinguish 2-3 clusters to which the samples corresponding to the single cases were assigned. These 2-3 clusters contained more than 80% of car on the average. Moreover, it was possible to correlate the change of cluster assignments with changes in lighting of car on the road. As the car enters the area of shadow, the visual perception of its colour is changing and so its cluster assignment. This effect is very welcome from our point of view since it makes clear evidence of cluster relevance.

On the basis of clustering new features were constructed for the objects. For each object (car) C_i ($i = 1, \dots, 18$) we construct new attributes na_1, \dots, na_c where c is the number of the clusters derived. The value of attribute na_j for the car C_i is the number of occurrences of an object representing i -th car in j -th cluster. So, if the value of attribute na_1 for car C_1 is 20 then we know that an object corresponding to this car was assigned to first cluster 20 times out of hundred. This new set of attributes undergone further analysis. By applying Rough Set based techniques it was possible to find out that attributes derived from clusters are sufficient for discernibility. Namely, it was possible, with the use of RSES software (see [41.7]), to calculate a set of *if..then..* decision rules classifying (discerning) the cars. In this way we got a simple set of rules such that there was exactly one rule for each of 18 cars.

Since clustering have led us to so promising results in terms of ability for object dissemination, we tried to exploit its potential to the limit. Since the clustering process takes some time in case of 1800 objects and 27 numerical attributes we were looking for the way to make it simpler. Reduction of computational effort is in our case very important since major part of recognition

process has to be performed on-line, during UAV operation. We found out that the clustering-based approach is quite powerful. We performed an experiment using reduced information about colour blobs. Instead of 27 attributes representing three RGB coordinates of 9 points (3×3 matrix) we take only three. These three are averages over 9 points for Red, Green and Blue coordinate values respectively. For this reduced set of features we obtained a clustering and it was still possible to have good discernibility between objects. Moreover, the time needed for computation was reduced several times.

The results presented above address the question about amount of useful information that can be retrieved from image sequences. The other question on our task list was the one about potential abilities for construction of classification system.

Initial experiments aimed at construction of classification method based on inductive learning of concepts were performed. We wanted to check what are the possibilities to create a system that will be able to classify previously unseen objects as being similar to the prototypes learned during presentation of training sample. For this purpose we first split our set of examples into halves. One half, used for training, contains first 50 samples for each car i.e. frames 1 to 50 from both image sequences. The remaining 50 frames from each sequence form the dataset used for testing. On the basis of training set we establish clustering-based features and decision rules using these features. Then we take a sample from the testing set and label them with the car numbers.

In the experiments we use simplified version of cluster-based attributes presented above. Instead of attributes na_1, \dots, na_c for training samples we take binary attributes ma_1, \dots, ma_c . Attribute ma_1 for a given sample is equal to 1 iff $na_1 > 0$ for this sample, and 0 otherwise.

Since we have to check abilities of classification system we start first with the learning phase. Learning of classification (decision) rules is done on the basis of 18 samples of 50 frames each. So the learning data consists of 18 objects, each object described by c attribute values, where c is the number of clusters.

First attempt was performed for testing samples consisting of entire 50 remaining frames. By matching those examples against previously created clusters, producing cluster-based attributes and the assigning decisions (car numbers) to the samples we got the result for training sample. In this particular experiment we got a perfect accuracy (100%).

Unfortunately, taking 50 frames requires approximately two seconds which is too long for real-time application. Therefore, we would like to be able to reduce the number of frames in testing sample to no more than 15-20 and still retain good classification ratio.

To do that we process our test data and produce testing samples with use of moving window. We set a size of the window to be some integer not greater than 50. Then from 50 frames we produce the testing sample by taking as many sequences of the size of window as possible and calculate cluster-related

attributes ma_1, \dots, ma_c for them. For instance, if we set the size of the window to be 15 then we will get 35 samples for each car. First of these samples will contain frames from 51 to 66 while the last will consist of frames 86 to 100. So, altogether for 18 cars we will get 830 testing instances.

The key is now to find the size of the window to at the same time small enough to allow on-line classification and big enough to have good quality of this classification. From several attempts we have learned that with the methods of attribute generation and decision rule derivation depicted above, we are able to get perfect accuracy of classification for testing sample if the size of the window exceeding 17. For the window size less than 17 the accuracy decreases, being 89% and 78% for the windows of size 16 and 15, respectively. It is worth mentioning that these experiments are, at the moment of writing, only initially finished. We expect to improve the results by allowing more information to be passed to classifier e.g. by using the original attributes na_1, \dots, na_c instead of simplified ma_1, \dots, ma_c .

41.6 Conclusions

The method for extracting information from image sequences was presented. It is based on combination of unsupervised clustering with Rough Set based approach. From the initial experiment we may see that this approach has a significant potential and may be further developed into complete solution. The proposed method have to be tuned to fit the requirements for co-operation with other components of UAV's control system as well as expectations about robustness, versatility and speed of operation.

The natural next step is the application of developed solutions to other sets of image data. We expect that some further evolution of the methods will be necessary, since many problems may arise. We believe that with more data we will be able to generalise our approach using tools such as more compound time series analysis.

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42. The Variable Precision Rough Set Inductive Logic Programming Model and Web Usage Graphs

V. Uma Maheswari, Arul Siromoney, and K.M. Mehata

Anna University, Chennai 600 025, India
asiro@vsnl.com

42.1 Introduction

Inductive Logic Programming [42.1] is the research area formed at the intersection of logic programming and machine learning. Rough set theory [42.2, 42.3] defines an indiscernibility relation, where certain subsets of examples cannot be distinguished. The gRS-ILP model [42.4] introduces a rough setting in Inductive Logic Programming and describes the situation where the background knowledge, declarative bias and evidence are such that it is not possible to induce any logic program from them that is able to distinguish between certain positive and negative examples. Any induced logic program will either cover both the positive and the negative examples in the group, or not cover the group at all, with both the positive and the negative examples in this group being left out.

The Variable Precision Rough Set (VPRS) model [42.5] is a generalized model of rough sets that inherits all basic mathematical properties of the original rough set model but allows for a controlled degree of misclassification. The Variable Precision Rough Set Inductive Logic Programming (VPRSILP) model [42.6] extends the gRS-ILP model using features of the VPRS model.

This paper applies the VPRSILP model to graphs, and presents the results of an illustrative experiment on web usage graphs.

42.2 The VPRSILP Model and Web Usage Graphs

The generic Rough Set Inductive Logic Programming (gRS-ILP) model introduces the basic definition of elementary sets in ILP [42.4, 42.7]. A parameter β , a real number in the range $(0.5, 1]$, is used in the VPRSILP model [42.6] as a threshold in elementary sets that have both positive and negative examples, to decide if that elementary set can be classified as positive or negative. A standard ILP algorithm GOLEM [42.8] is modified in [42.6] to fit this model. The formal definitions and the modified algorithm are omitted here due to space constraints.

42.2.1 A Simple–Graph–VPRSILP–ESD System

Let U be a universe of examples. Let a graph G_x be associated with every x in U . Let $G_U = (N_U, E_U)$ be a graph associated with the universe such that G_x , for every $x \in U$, is a subgraph of G_U . N_U is the set of nodes and E_U is the set of links of G_U .

Definition 42.2.1. We define a simple–graph–VPRSILP–ESD system as a 2-tuple $S = (S', G_U)$, where:

(1) G_U is a directed graph, and

(2) $S' = (E, B, L, \beta)$ is a VPRSILP–ESD system [42.6] such that

(i) E is the universe of examples consisting of a unary predicate, say p .

Each example $p(x)$ has a directed graph G_x associated with it which is a subgraph of G_U

(ii) B is the background knowledge consisting of ground unit clauses, using the following predicate:

edge (of arity 3) where for any $p(x) \in E$:

$edge(x, sourcenode, destnode) \in B \Rightarrow$ the graph associated with the example $p(x)$ has an edge from the sourcenode to destnode.

(iii) L is the declarative bias $L = L_{pi} \wedge L_{rd} \wedge L_{eu}$, (defined in [42.7])

(iv) β is a real number in the range $(0.5, 1]$.

Our aim is to find a hypothesis H such that

$P = B \wedge H \in \mathcal{P}_\beta(S)$, the β –restricted program space [42.6].

42.2.2 Web Usage Graphs

We now consider an example of a simple–graph–VPRSILP–ESD system using Web usage graphs. Let us consider a particular set of Web pages and links between them. Each node in N_U corresponds to one of these Web pages and each link in E_U corresponds to one of these links. A single session x when a user enters any Web page in N_U till the user finally leaves the set of Web pages in N_U is a subgraph of $G_U = (N_U, E_U)$, denoted by $G_x = (N_x, E_x)$.

The universe U is considered to be the set of all such sessions. A session $x \in U$ is a positive example ($x \in X$) or a negative example ($x \in (U - X)$) based on some concept of interest (X).

The notion of Posgraph and Neggraph (that cumulatively capture all known positive and negative sessions) is introduced in [42.9]. Using Posgraph (Neggraph), edges that are distinctly present in the positive (negative) sessions are obtained. These edges are considered to be important and used in predicting unknown sessions.

Let G_U be the weighted directed graph representing the Web pages and links under consideration. Let $E = E^+ \cup E^-$, $E^+ = \{p(e1), p(e2)\}$, $E^- = \{p(e3)\}$. Let $B = \{edge(e1, //m.org/a, //m.org/b), edge(e1, //m.org/c, //m.org/d), edge(e2, //m.org/c, //m.org/d), edge(e3, //m.org/b, //m.org/c)\}$.

$S = (S', G_U)$, where $S' = (E, B, L_{pi} \wedge L_{rd} \wedge L_{eu}, \beta)$, is a simple-graph-VPRSILP-ESD system. One induced hypothesis H , such that $P = H \wedge B \in \mathcal{P}_\beta(S)$, for $\beta = 0.5$, is of the form

$p(X) : \text{-edge}(X, //m.org/a, //m.org/b), \text{edge}(X, //m.org/c, //m.org/d)$.

It is seen that for $P = B \wedge H$, $P \vdash p(e1)$, $P \not\vdash p(e2)$, $P \not\vdash p(e3)$.

42.3 Experimental Illustration

The dataset used in our experiment is taken from the website <http://www.cs.washington.edu/research/adaptive/download.html> and is the data set used in [42.10, 42.11]. The data pertains to web access logs at the site <http://machines.hyperreal.org> during the months of September and October 1997. Each day of the month has a separate file. Each file records all the requests for Web pages made to the Web server on that particular day. Sessions with less than 3 edges or more than 499 edges were not considered.

The dataset (U) is divided into positive example sessions (X) and negative example sessions ($U - X$). As an illustration, all sessions that had an access from www.paia.com are treated as positive examples and all sessions that had access from www.synthzone.com as negative examples.

The data is first preprocessed to determine a set of useful edges based on the number of positive and negative sessions traversing the edges. The universal graph G_U consists of these useful edges.

Each elementary set corresponds to the set of examples whose session graphs have the same set of edges in G_U . The training set is used to determine the number of positive and negative examples in each elementary set.

In the modified GOLEM algorithm [42.6] all elementary sets covered by any rule fall within the β -positive region. A β value of 0.5 is used in this experiment. The two counters in each elementary set are used to calculate the conditional probability, and hence to determine whether the elementary set is in the β -positive region or β -negative region.

The modified GOLEM algorithm is implemented with the following changes. (1) For each session, the corresponding elementary set is determined based on which of the useful edges are traversed in that session. (2) The maximal common subgraph between example sessions is used instead of rlgg. (3) Every example is used rather than a random subset. (4) The innermost loop is not implemented, since every example is being considered.

Ten fold cross validation was done by using days ending with 0, 1, 2, ..., 9 as the ten sets. The experiment consists of two separate runs. The first run uses the original positive and negative examples, whereas the second run uses the original negative examples as the positive examples, and the original positive examples as the negative examples. In other words, the positive and negative examples are inverted in the second run. The results of the ten fold cross validation in the original run (original positive and negative examples) are tabulated below.

Serial	Positives		Negatives	
	Correct	Wrong	Correct	Wrong
0	20	33	294	0
1	24	19	134	2
2	18	32	215	0
3	24	47	285	0
4	20	42	219	1
5	34	27	209	0
6	30	32	294	1
7	18	34	192	0
8	19	35	205	0
9	29	34	320	3
Average	23.6	33.5	236.7	0.7

The results of the ten fold cross validation in the inverted run are tabulated below. The original positive and negative examples are inverted and are used as negative and positive examples, respectively.

Serial	Positives		Negatives	
	Correct	Wrong	Correct	Wrong
0	68	226	52	1
1	33	103	42	1
2	56	159	50	0
3	83	202	71	0
4	47	173	62	0
5	62	147	60	1
6	66	229	62	0
7	58	134	51	1
8	55	150	51	3
9	63	260	62	1
Average	59.1	178.3	56.3	0.8

The average results in the two runs are tabulated below. The following table is the average result of the ten-fold cross-validation on the original positive and negative examples.

	Pred. Pos	Pred. Neg
Actually Positive	23.6	33.5
Actually Negative	0.7	236.7

The following table is the average result of the ten-fold cross-validation on the inverted positive and negative examples. It is to be noted that the positives and negatives reported in the table are the original positives and negatives (i.e. reinverted from those used in the actual inverted run).

	Pred. Pos	Pred. Neg
Actually Positive	56.3	0.8
Actually Negative	178.3	59.1

It is seen from the tables, that in the original run, if a test case is predicted positive, it has 97.1% chance of being positive; and in the inverted run, if a test case is predicted as original negative, it has 98.7% chance of being an original negative. (This high degree of accuracy of prediction applies to the 41.3% of the positive test cases that are predicted positive and the 24.9% of the negative test cases that are predicted negative.)

42.4 Conclusions

The VPRSILP model is applied to Web usage graphs. An illustrative experiment on the prediction of Web usage sessions is presented. Possibilities for further work include the application of the VPRSILP model to other ILP algorithms and to other application areas.

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43. Optimistic Priority Weights with an Interval Comparison Matrix

Tomoe Entani¹, Hidetomo Ichihashi¹ and Hideo Tanaka²

¹ Graduate School of Engineering, Osaka Prefecture University,
1-1 Gakuen-cho, Sakai, Osaka, 599-8531 Japan
entani@ie.osakafu-u.ac.jp

² Graduate School of Management and Information, Toyohashi Sozo College,
20-1 Matsushita, Ushikawa-cho, Toyohashi, Aichi, 440-8511

AHP is proposed to give the importance grade with respect to many items. The comparison value is used to be crisp, however, it is easy for a decision maker to give it as an interval. The interval comparison values can reflect uncertainty due to human judgement. In this paper, the interval importance grade is obtained from an interval comparison matrix so as to include the decision maker's judgement. To choose the crisp importance grades and the crisp efficiency in the decision maker's judgement, we use DEA, which is an evaluation method from the optimistic viewpoint.

43.1 Introduction

AHP (Analytic Hierarchical Process) is proposed to determine the importance grades of each item [43.1]. AHP is a method to deal with the importance grades with respect to many items. In conventional AHP, the crisp importance grade of each item can be obtained by solving eigenvector problem with a crisp comparison matrix. Since a decision maker's judgement is uncertain and it is easier for him/her to give it as an interval value than to give it as a crisp value, we extend the crisp comparison values to intervals.

Based on the idea that a comparison matrix is inconsistent due to human judgements, the model that gives the importance grade as an interval is proposed [43.2]. We take another way to obtain the interval importance grades based on eigenvector method and interval regression analysis[43.3]. When a decision maker gives comparison matrices for input and output items, the interval importance grades of input and output items are obtained respectively. The obtained interval importance grades can be considered as the acceptable importance grades for a decision maker.

We choose the most optimistic importance grades for the analyzed object in the interval by DEA (Data Envelopment Analysis) [43.4][43.5]. DEA is a well-known method to evaluate DMUs (Decision Making Units) from the optimistic viewpoint. The weights in DEA and the importance grades through AHP are similar then DEA is used to choose the most optimistic importance grades of input and output items in the decision maker's acceptable ranges[43.6]. Our aim is to choose the importance grades in a possible ranges which are estimated from a decision maker's judgement.

43.2 Interval AHP with Interval Comparison Matrix

When a decision maker compares a pair of items for all possible pairs with n items, I_1, \dots, I_n , we can obtain a comparison matrix A as follows. A decision maker's judgement is usually uncertain. Therefore, it is more suitable to give the comparison values as intervals.

$$A = \begin{pmatrix} 1 & \dots & [{}^L a_{1n}, {}^U a_{1n}] \\ \vdots & [{}^L a_{ij}, {}^U a_{ij}] & \vdots \\ [{}^L a_{n1}, {}^U a_{n1}] & \dots & 1 \end{pmatrix}$$

where the element of matrix A , $[{}^L a_{ij}, {}^U a_{ij}]$, shows the importance grade of I_i obtained by comparing with I_j , the diagonal elements are equal to 1, that is ${}^L a_{ii} = {}^U a_{ii} = 1$ and the reciprocal property is satisfied, that is ${}^L a_{ij} = 1/{}^U a_{ji}$.

Then, we estimate the importance grade of item i , as an interval denoted as W_i , that is determined by its center w_i^c and its radius d_i as follows.

$$W_i = [{}^L w_i, {}^U w_i] = [w_i^c - d_i, w_i^c + d_i]$$

In order to determine interval importance grades, we have two problems where one is to obtain the center and the other is to obtain the radius. The center is obtained by eigenvector method with the obtained comparison matrix A . Since the elements of A are intervals, their centers are used. The eigenvector problem is formulated as follows.

$$Aw = \lambda w \tag{43.1}$$

Solving (43.1), the eigenvector (w_1^c, \dots, w_n^c) for the principal eigenvalue λ_{max} is obtained as the center of the interval importance grade of each item. The center w_i^{c*} is normalized to be $\sum_{i=1}^n w_i^{c*} = 1$.

The radius is obtained based on interval regression analysis, which is to find the estimated intervals to include the original data. In our problem, a_{ij} is approximated as an interval ratio such that the following relation holds.

$$[{}^L a_{ij}, {}^U a_{ij}] \subseteq \frac{W_i}{W_j} = \left[\frac{w_i^{c*} - d_i}{w_j^{c*} + d_j}, \frac{w_i^{c*} + d_i}{w_j^{c*} - d_j} \right] \tag{43.2}$$

where W_i/W_j is defined as the maximum range.

The interval importance grades are determined to include the interval comparison values. Using the obtained centers w_i^{c*} by (43.1), the radius should be minimized subject to the constraint conditions that the relation (43.2) for all elements should be satisfied.

$$\begin{aligned} & \min \quad \lambda \\ \text{s.t.} \quad & \frac{w_i^{c*} - d_i}{w_j^{c*} + d_j} \leq {}^L a_{ij}, \quad {}^U a_{ij} \leq \frac{w_i^{c*} + d_i}{w_j^{c*} - d_j}, \quad (\forall (i, j)) \\ & d_i \leq \lambda, \quad (\forall i) \end{aligned} \tag{43.3}$$

The interval importance grade shows the acceptable range for a decision maker.

43.3 Choice of Optimistic Weights and Efficiency by DEA

43.3.1 DEA with Normalized Data

In DEA the maximum ratio of output data to input data is assumed as the efficiency which is calculated from the optimistic viewpoint for each DMU. The basic DEA model is formulated as follows.

$$\begin{aligned} \theta_o^{E*} &= \max_{\mathbf{u}} \mathbf{u}^t \mathbf{y}_o \\ \text{s.t. } &\mathbf{v}^t \mathbf{x}_o = 1 \\ &-\mathbf{v}^t X + \mathbf{u}^t Y \leq \mathbf{0} \\ &\mathbf{u}, \mathbf{v} \geq \mathbf{0} \end{aligned} \quad (43.4)$$

where the decision variables are the weight vectors \mathbf{u} and \mathbf{v} , $X \in \Re^{m \times n}$ and $Y \in \Re^{k \times n}$ are input and output matrices consisting of all input and output vectors that are all positive and the number of DMUs is n .

In the conventional DEA as in (43.4), it is difficult to compare importance of input and output items to their weights, because the weights largely depend on the scales of the original data X and Y . Then we normalize the given input and output data based on DMU_o so that the input and output weights represent the importance grades of the items.

The normalized input and output denoted as \hat{x}_{jp} and \hat{y}_{jr} are obtained as follows.

$$\hat{x}_{jp} = x_{jp}/x_{op}, \quad \hat{y}_{jr} = y_{jr}/y_{or}$$

The problem to obtain the efficiency with the normalized input and output are formulated as follows.

$$\begin{aligned} \theta_o^{E*} &= \max_{\hat{\mathbf{u}}} (\hat{u}_1 + \cdots + \hat{u}_k) \\ \text{s.t. } &\hat{\mathbf{v}}_1 + \cdots + \hat{\mathbf{v}}_m = 1 \\ &-\hat{\mathbf{v}}^t \hat{X} + \hat{\mathbf{u}}^t \hat{Y} \leq \mathbf{0} \\ &\hat{\mathbf{u}}, \hat{\mathbf{v}} \geq \mathbf{0} \end{aligned} \quad (43.5)$$

where \hat{X} and \hat{Y} are all the normalized data and $\hat{\mathbf{u}}$ and $\hat{\mathbf{v}}$ are the decision variables. The efficiency from the normalized input and output is equal to that from the original data by conventional DEA. The obtained weight represents the importance grade itself. Then we can use DEA with the normalized data to choose the optimistic weight in the interval importance grade obtained by a decision maker through interval AHP.

43.3.2 Optimistic Importance Grades in Interval Importance Grades

A decision maker gives comparison values for all pairs of input and output items and the comparison matrices for input and output items whose elements are $[^L a_{ij}^{in}, ^U a_{ij}^{in}]$ and $[^L a_{ij}^{out}, ^U a_{ij}^{out}]$ are obtained.

By the proposed interval AHP in 43.2, the importance grades of input and output items are denoted as follows.

$$W_p^{in} = [Lw_p^{in}, U w_p^{in}], \quad W_r^{out} = [Lw_r^{out}, U w_r^{out}]$$

The optimistic or substitutional weights and efficiency are obtained by considering the interval importance grades through interval AHP as the weight constraints in DEA with the normalized data. By DEA, we can determine the optimistic weights for DMU_o in the possible ranges. The constraint conditions for the input and output weights are as follows, considering the difference between sums of centers of the interval importance grades and weights.

$$Lw_r^{out} \leq \frac{\hat{u}_r}{(\hat{u}_1 + \dots + \hat{u}_k)} \leq U w_r^{out}, \quad Lw_p^{in} \leq \hat{v}_p \leq U w_p^{in} \tag{43.6}$$

The problem to choose the most optimistic weights for DMU_o in the decision maker’s judgement is formulated by adding (43.6) to (43.5) as the constraint conditions. Any optimal solutions are within the interval importance grades that are given by a decision maker based on his/her evaluation. As the character of DEA the optimal weights are obtained from the most optimistic viewpoint for DMU_o . Therefore both of a decision maker and DMUs are satisfied with the obtained evaluations.

43.4 Numerical Example

1-input and 4-output data of example DMUs(A,...,J) are shown in Table 43.1. The interval comparison matrix given by a decision maker and the interval

Table 43.1. Data with 1-input and 4-output and efficiencies

	x_1	y_1	y_2	y_3	y_4	DEA	proposed model
A	1	1	8	1	3	1.000	0.925
B	1	2	3	4	4	0.850	0.703
C	1	2	6	6	1	1.000	0.670
D	1	3	3	5	5	1.000	0.753
E	1	3	7	4	2	1.000	1.000
F	1	4	2	3	1	0.706	0.376
G	1	4	5	5	3	1.000	0.954
H	1	5	2	1	6	1.000	0.548
I	1	6	2	7	1	1.000	0.381
J	1	7	1	2	5	1.000	0.294

importance grades by (43.1) and (43.3) are shown in Table 43.2. Interval importance grades reflect inconsistency in the given interval comparison matrix.

Table 43.2. Comparison matrix and importance grades of output items

	y_1	y_2	y_3	y_4	centers	importance grades
y_1	1	[1/6,1/3]	[3,7]	[1/6,1/2]	0.135	[0.071,0.200]
y_2	[3,6]	1	[6,8]	[2,4]	0.522	[0.391,0.652]
y_3	[1/7,1/3]	[1/8,1/6]	1	[1/3,1/9]	0.049	[0.029,0.070]
y_4	[2,6]	[1/4,1/2]	[3,9]	1	0.294	[0.163,0.424]

Within the given interval importance grades DMUs are evaluated and their efficiencies obtained by the proposed model (43.6) with (43.5) are shown in Table 43.1. The efficiency through the proposed model can be obtained from the optimistic viewpoint within a decision maker's acceptable importance grades. Therefore, the efficiencies in the proposed model are smaller than those in conventional DEA.

43.5 Concluding Remarks

In this paper, we dealt with an interval comparison matrix that contains a decision maker's uncertain judgements and obtained the interval importance grade of each item through interval AHP. Then, using DEA, we chose the most optimistic weights for DMU_o within the interval importance grades obtained by a decision maker. A decision maker's evaluation and a DMU's opinion are taken into consideration by interval AHP and DEA respectively.

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44. Rough Set Theory in Conflict Analysis

Rafał Deja¹ and Dominik Ślęzak²

¹ Tokarskiego 4/14, 40-749 Katowice, Poland, rd@alta.pl

² Institute of Mathematics, Warsaw University Banacha 2, 02-097 Warsaw, Poland

44.1 Introduction

The importance of multi-agents systems, models of agents' interaction is increasing nowadays as distributed systems of computers started to play a significant role in society. An interaction occurs when two or more agents, which have to act in order to attain their objectives, are brought into a dynamic relationship. This relationship is the consequence of the limited resources which are available to them in a situation. If the number of resources is insufficient to attain agents' goals it often comes into the conflicts. This can happen in almost all industrial activities requiring distributed approach, such as network control, the design and manufacture of industrial products or the distributed regulation of autonomous robots. However, distributed systems is only one from many different areas where a conflict can arise and where it is worth to apply computer aided conflict analysis. Just to mention some human activities like business, government, political or military operations, labour-management negotiations etc. etc.

In the paper, we explain the nature of conflict and we define the conflict situation model in a way to encapsulate the conflict components in a clear manner. We propose some methods to solve the most fundamental problems related to conflicts.

Pawlak Model

The model introduced in this paper is an enhancement of the model proposed by Pawlak in papers e.g. [44.6, 44.8]. In the Pawlak model, some issues are chosen, and the agents are asked to specify their views: are they favourable, neutral or against. Thus the analysis are naturally restricted to outermost conclusions like finding the most conflicting attributes or the coalitions of agents if more than two take part in the conflict [44.8]. In the real world, views on the issues to vote are consequences of the decision taken, based on the local issues, the current state and some background knowledge using some strategy. Therefore, the Pawlak model is enhanced here by adding to the model some local aspects of conflicts.

44.2 Conflict Model

The information about the *local states* U_{ag} of an agent ag can be presented in the form of an information table, creating the agent ag 's information system $I_{ag}=(U_{ag}, A_{ag})$, where $a: U_{ag} \rightarrow V_a$ for any $a \in A_{ag}$ and V_a is the value set of attribute a . We assume: $V_{ag} = \bigcup_{a \in A_{ag}} V_a$. Any local state $s \in U_{ag}$ is explicitly described by its *information vector* $Inf_{A_{ag}}(s)$, where $Inf_{A_{ag}}(s) = \{(a, a(s)) : a \in A_{ag}\}$. The set $Inf_{A_{ag}}(s) : s \in U_{ag}$ is denoted by $INF_{A_{ag}}$ and it is called the *information vector set of ag*. We assume that sets $\{A_{ag}\}$ are pairwise disjoint, i.e., $A_{ag} \cap A_{ag'} = \emptyset$ for $ag \neq ag'$. This condition emphasizes that any agent is describing the situation in its own way. Relationships among attributes of different agents will be defined by constraints as shown in section 0.

Local Set of Goals (Similarity of States)

Every agent evaluates the local states. The *subjective evaluation* corresponds to an order (or partial order) of the states of the agent information table. We assume that the function e_{ag} called the *target function*, assigns an evaluation score to each state; let for example $e_{ag}: U_{ag} \rightarrow [0,1]$. The states with score 1 are mostly preferred by the agent as target states, while the states with score 0 are not acceptable. Maximal elements (determined by an partial order) can be interpreted as those, which are targets of the agent, i.e., the agent wants to reach them e.g. in a negotiation process.

More precisely the agent ag 's *set of goals (targets)* denoted by $T(ag)$ is defined as the set of target states of ag , which means $T_{ag} = \{s \in U_{ag} : e_{ag}(s) > \mu_{ag}\}$, and μ_{ag} is the *acceptance level*, chosen by the agent ag – it is subjective which evaluation level is acceptable by the agent.

The state evaluation can also help us to find the state similarity [44.4]. For any $\varepsilon > 0$ and $s \in U_{ag}$, we define ε -*neighbourhood* of s by: $\tau_{ag, \varepsilon}(s) = \{s' \in U_{ag} : |e_{ag}(s) - e_{ag}(s')| \leq \varepsilon\}$. The family $\{\tau_{ag, \varepsilon}(s)\}_{s \in U_{ag}}$ defines a tolerance relation $\tau_{ag, \varepsilon}(s)$ in $U_{ag} \times U_{ag}$ by $s \tau_{ag, \varepsilon} s'$ iff $s' \in \tau_{ag, \varepsilon}(s)$.

Local Conflict

The agent ag is in the ε -*local conflict* in a state s iff s does not belong to the ε -neighbourhood of s' , for any s' from the set of ag -targets where ε is a given threshold. Local conflicts for an agent ag arise from the low level of subjective evaluation of the current state by ag . It can be expressed differently that the state s does not belong to the ε -environs of the set of goals T_{ag} i.e.: $s \notin \bigcup_{s' \in T_{ag}} \tau_{ag, \varepsilon}(s')$,

where $\tau_{ag, \varepsilon}(s') = \{s'' : s'' \tau_{ag, \varepsilon} s'\}$.

Situation

Let us consider a set Ag consisting of n agents ag_1, \dots, ag_n . A *situation* of Ag is any element of the Cartesian product $S(Ag) = \prod_{i=1}^n INF^*(ag_i)$, where $INF^*(ag_i)$ is the set of all possible information vectors of agent ag_i , defined by: $INF^*(ag) = \{f : A_{ag} \rightarrow \bigcup_{a \in A_{ag}} V_a(ag) : f(a) \in V_a(ag) \text{ for } a \in A_{ag}\}$. The *situation* S corresponding to a global state $\bar{s} = (s_1, \dots, s_n) \in U_{ag_1} \times \dots \times U_{ag_n}$ is defined by $(Inf_{A_{ag_1}}(s_1), \dots, Inf_{A_{ag_n}}(s_n))$.

Constraints

Constraints are described by some dependencies among local states of agents. Without any dependencies, any agent could take the state freely and there is no conflict at all. Dependencies come from the bound on the number of resources (any kind of a resource may be considered, e.g. water on Golan Hills see [44.8] or an international position [44.5], everything that is essential for agents). Constraining relations are introduced to express which local states of agents can coexist in the (global) situation. More precisely, *constraints* are used to define a subset $S(Ag)$ of global situations. Constraints restrict the set of possible situations to admissible situations satisfying constraints.

Situations Evaluation

Usually agents tend to attain the best states without taking care about the *global good*. However, the negotiators experience shows that the real, stable consensus can only be found when the global good is considered. Thus the *objective evaluation of situations* is introduced – an expert (an arbiter) judgement. For example, the United Nation Organisation can be thought as an expert in the military conflicts.

We assume there is a function $q: S_{Ag} \rightarrow [0, 1]$, called the *quality function*, which assigns a score to each situation (this score is assume to be given by an expert). The set of situations satisfying a given level of quality t is defined by: $Score_{Ag}(t) = \{S \in S(Ag) : q(S) \geq t\}$

System with Constraints

The multi-agent system, with local states for each agent defined and the global situations satisfying constraints, will be called *the system with constraints*. We denote our system with constraints by M_{Ag} .

44.3 Analysis

The introduced above conflict model gives us possibility, first to understand and, then, to analyse different kinds of conflicts. Particularly, the most fundamental problem can be widely investigated, that is, the possibility to achieve the consensus. Because of the lack of space only the consensus problem on local preferences is described in this paper. We propose Boolean reasoning [44.1] and Rough Set methodology [44.7] for all analysis. The main idea of Boolean reasoning is to encode the optimisation problem, by corresponding Boolean function f_π in such a way that any prime implicant of f_π states a solution of π . The elementary Boolean formula is usually obtained here by transforming the information table into the decision table, generating rules (minimal with respect of number of attributes on left side) and determining the description of decision class 44.9. From the elementary formulas the final formula describing the problem is shaped.

Unfortunately calculating prime implicants of such formulas is usually a hard-computational problem [44.4]. Therefore depending on the formula, some simple strategies or eventually quite complex heuristics must be used to resolve the problem in real time.

Consensus Problem on Local and Global Level

In this point a conflict analysis is proposed where local information tables and the set of local goals are taken into consideration.

INPUT

The system with constraints M_{Ag} defined in Section 0.

t - an acceptable threshold of the objective global conflict for Ag .

OUTPUT

All situations with the objective evaluation reduced to degree at most t , and without local conflict for any agent. (it is required that any new situation is constructed in the way that all local states in this situation are favourable for the agents).

ALGORITHM

The algorithm is based on verification of global situations from $Score_{Ag}(t)$ with the local set of goals of agents and constraints. The problem is described by the formula

$f: f = \bigwedge_{ag \in Ag} t_{ag} \wedge f_c \wedge f_\varphi$, where t_{ag} describes the set of goals of the agent ag ,

and f_c describes $Score_{Ag}(t)$ and f_φ the constraints. The formula $f_c \wedge f_\varphi$ representing all admissible situations without the global conflict regarding the threshold t .

44.4 Conclusions

We have presented and discussed the extension of the Pawlak conflict model. The understanding of the underlying local states as well as constraints in the given situation is the basis for any analysis of our world. The local goals and the evalua-

tion of the global situation are observed as factors defining the strength of the conflict and can suggest the way to reach the consensus.

The fundamental consensus problem has been analysed in the paper. Then, Boolean reasoning and rough set theory has been successfully applied for solving presented problem. The lack of space not allowed the authors to present any conflict example – see [44.2] for some exemplar conflict analysis within proposed model.

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45. Dealing with Imperfect Data by RS-ILP

Chunnian Liu¹ and Ning Zhong²

¹ School of Computer Science, Beijing Polytechnic University, China
cslcn@bjpu.edu.cn

² Dept. of Information Eng., Maebashi Institute of Technology, Japan
zhong@maebashi-it.ac.jp

Rough Set theory and Granular Computing (GrC) have a great impact on the study of intelligent information systems. This paper investigates the feasibility of applying Rough Set theory and Granular Computing (GrC) to deal with imperfect data in Inductive Logic Programming (ILP). We propose a hybrid approach, RS-ILP, to deal with some kinds of imperfect data which occur in real-world applications.

45.1 Introduction

Inductive Logic Programming (ILP, see [45.2, 45.7, 45.8]) can be regarded as a new method in machine learning with the advantages of more expressive power and ease of using background knowledge. If databases are involved, ILP is also relevant to Knowledge Discovery and Data Mining (KDD, see [45.1, 45.3]). In a simplified form, the normal problem setting of ILP is as follows:

Given:

- The target predicate p .
- The positive examples E^+ and the negative examples E^- (two sets of ground atoms of p).
- Background knowledge B (a finite set of definite clauses).

To find:

- Hypothesis H (the defining clauses of p) which is *correct* with respect to E^+ and E^- , i.e.
 1. $H \cup B$ is *complete* with respect to E^+ (that is: For all $e \in E^+$, $H \cup B$ implies e). We also say that $H \cup B$ *covers* all positive examples.
 2. $H \cup B$ is *consistent* with respect to E^- (that is: For no $e \in E^-$, $H \cup B$ implies e). We also say that $H \cup B$ *rejects* any negative examples.

To make the ILP problem meaningful, we assume the following prior conditions:

1. B is not complete with respect to E^+ (Otherwise there will be no learning task at all, because the background knowledge itself is the solution).
2. $B \cup E^+$ is consistent with respect to E^- (Otherwise there will be no solution to the learning task).

In the above normal problem setting for ILP, everything is assumed correct and perfect. But in large, real-world empirical learning, data are not always perfect. In contrary, uncertainty, incompleteness, vagueness, imprecision, etc. are frequently observed in the input to ILP – the training examples and/or background knowledge. Imperfect input, in addition to improper bias setting, will induce imperfect hypotheses. Thus ILP has to deal with imperfect data. In this aspect, the theory, measurement, techniques and experiences are much less mature for ILP than in the traditional attribute-value learning methods (compare [45.12], for example).

We observe that many problems concerning imperfect input or too strong bias in ILP have a common feature. In these situations, while it is impossible to differentiate distinct objects, we may consider *granules* – sets of objects drawn together by similarity, indistinguishability, or functionality. The emerging theory of *Granular Computing (GrC)* (see [45.15, 45.16, 45.14]) grasps the essential concept – granules, and makes use of them in general problem solving.

In this paper we concentrate on a particular form of *GrC*, Pawlak's Rough Set theory [45.9, 45.10, 45.11], investigating its potentials in dealing with imperfect data of ILP. The main idea is that, when we use granules instead of individual objects, we are actually relaxing the strict requirements in the standard normal problem setting for ILP. In the following sections, we will discuss some kinds of imperfect data in ILP and propose a hybrid approach, RS-ILP, as a solution using Rough Set theory, to deal with such imperfect data.

45.2 Imperfect Data in ILP

We discuss here two kinds of imperfect data encountered in ILP as examples.

– Incomplete background knowledge.

Background knowledge B is essential in ILP learning, and the ease of using background knowledge is one of the major advantages of ILP over traditional attribute-value learning methods. However, if B lacks essential predicates (or essential clauses of some predicates), it is possible that no non-trivial hypothesis H can be induced. (Note that E^+ itself can be always regarded as a hypothesis, but it is trivial). In some cases, even a large amount of positive examples are given, some examples are not generalized by hypotheses if some background knowledge is missing. This has been a big topic in the research area of ILP.

– Missing classification.

This means that some examples have unknown classification values (i.e., we do not know if an example belongs to E^+ or E^-). Here we have a set of classified training instances $E^+ \cup E^-$ and a set of unclassified instances $E^?$. If the classified set is small and the unclassified set $E^?$ is ignored, we

are facing with the problem of *too sparse data* to induce reliable hypothesis H . But here we have got a set of additional examples $E^?$ though we don't know their classification. The challenge is how to utilize our knowledge about $E^?$ to induce more reliable hypotheses. One approach is to combine learning and conceptual clustering techniques (see [45.2]): a conceptual clustering algorithm is applied to the set of all known examples, climbing the hierarchytree, using the classified examples to identify class descriptions forming H .

We have proposed several rough problem settings of ILP (RS-ILP for short) to deal with such imperfect data. The key idea is to relax the requirement in the normal problem setting that H should be “correct with respect to E^+ and E^- ”, so that rough but useful hypotheses can be induced. Some of them will be discussed in the following sections.

45.3 RS-ILP for Missing Classification

If $E^+ \cup E^-$ is a small set, we cannot expect that the induced hypothesis H will have high prediction accuracy. Sometimes we may have an additional set of examples $E^?$ that are unclassified (that is, we do not know whether these examples belong to E^+ or E^-). Can we utilize $E^?$ to increase the prediction accuracy? We propose the following rough problem setting for this purpose:

Given:

- The target predicate p (the set of all ground atoms of p is U).
- An equivalence relation R on U (we have the approximation space $A = (U, R)$).
- A set of positive examples $E^+ \subseteq U$ and A set of negative examples $E^- \subseteq U$.
- A set of unclassified examples $E^? \subseteq U$.
- Background knowledge B .

Considering the following rough sets:

1. $E^{+?} = E^+ \cup \{e^? \in E^? \mid \exists e \in E^+ eRe^?\}$;
2. $E^{-?} = E^- \cup \{e^? \in E^? \mid \exists e \in E^- eRe^?\}$.

To find:

- Hypothesis $H^?$ (the defining clauses of p) which is correct with respect to $E^{+?}$ and $E^{-?}$. That is,
 1. $H^? \cup B$ covers all examples of $E^{+?}$;
 2. $H^? \cup B$ rejects all examples of $E^{-?}$.

In such rough problem setting, we use equivalence relation R to “enlarge” the training set (by distributing some examples from $E^?$ to E^+ and E^-). Different R will produce different hypothesis $H^?$. It is reasonable to expect

that the more unclassified examples are added to E^+ , the more general hypothesis will be induced; the more unclassified examples are added to E^- , the more specific hypothesis will be induced.

45.4 RS-ILP for Too Strong Bias

Declarative bias (restrictions on the hypothesis space and/or on the search strategies) is necessary in any inductive learning (so in ILP). Clearly, there is a trade-off between the tractability of search, which is improved by a small search space, and the availability of a correct hypothesis, which is improved by a large search space. Particularly, if the bias is too strong, we may miss some useful solutions or have no solution at all. Most ILP systems provide mechanisms for the user to specify bias, and allow the user to change bias (weakening the restrictions when the current ILP session fails). This strategy is called *bias shift*.

Here we investigate this problem from another point of view. Supposing that the training set $E^+ \cup E^-$ and the background knowledge B are perfect, but if we restrict the hypotheses to *non-recursive* clauses (a bias often imposed in some ILP systems), we still could not find any meaningful hypothesis in the normal problem setting of ILP. However, relaxing the requirement in the normal problem setting of ILP that H should be “correct with respect to E^+ and E^- ”, in order to find a “rough” solution that is within the language defined by the bias.

45.5 Concluding Remarks

This paper addressed the problem of imperfect data handling in Inductive Logic Programming (ILP) using some ideas, concepts and methods of Rough Set theory and GrC. We presented a hybrid approach, RS-ILP, to deal with some kinds of imperfect data which occur in large real-world applications. Although some part of this work is still in the initial shape, we believe that the general ideas presented here may give rise to more concrete results in future research. Future work in this direction includes finding more concrete formalisms and methods to deal with other kinds of imperfect data, and giving quantitative measures associated with hypotheses induced of RS-ILP.

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46. Extracting Patterns Using Information Granules: A Brief Introduction

Andrzej Skowron¹, Jarosław Stepaniuk², and James F. Peters³

¹ Institute of Mathematics, Warsaw University, 02-097 Banacha 2, Warsaw, Poland, skowron@mimuw.edu.pl

² Institute of Computer Science, Białystok University of Technology, Wiejska 45A, 15-351 Białystok, Poland, jstepan@ii.pb.bialystok.pl

³ Computer Engineering, University of Manitoba, Winnipeg, MB R3T 5V6 Canada, jfpeters@ee.umanitoba.ca

The paper realizes a step in developing a foundation for approximate reasoning from experimental data to conclusions in natural language. Granule decomposition strategies based on background knowledge are outlined.

46.1 Introduction

Information granulation belongs to a collection of intensively studied topics in soft computing (see, e.g., [46.19], [46.20], [46.21]). One of the recently emerging approaches to deal with information granulation is based on information granule calculi (see, e.g., [46.10], [46.12], [46.15], [46.13]) developed on the basis of the rough set [46.6] and rough mereological approaches (see, e.g., [46.9], [46.10], [46.12]). The development of such calculi is important for making progress in many areas like object identification by autonomous systems (see, e.g., [46.1], [46.18]), web mining (see, e.g., [46.4]), approximate reasoning based on information granules (see, e.g., [46.15], [46.7]) or spatial reasoning (see, e.g., [46.2], [46.8]). In particular, reasoning methods using background knowledge as well as knowledge extracted from experimental data (e.g., sensor measurements) represented by concept approximations [46.1] are important for making progress in such areas.

Schemes of approximate reasoning (AR-schemes, for short) are derived from parameterized productions [46.11], [46.13]. The productions, specifying properties of operations on information granules, are assumed to be extracted from experimental data and background knowledge. The problem of AR-schemes deriving is closely related to perception (see, e.g., [46.21]). In the paper we outline some methods for decomposition of information granules.

46.2 Granule Decomposition

In this section, we discuss briefly a granule decomposition problem. This is one of the basic problems in synthesis of approximate schemes of reasoning

from experimental data. We restrict our considerations to the case of information granule decomposition supported by background knowledge. Some other decomposition methods are presented in [46.9], [46.5].

Assume that a knowledge base consists of a fact expressing that if two objects belong to concepts C_1 and C_2 , then the object constructed out of them by means of a given operation f belongs to the concept C provided that the two objects satisfy some constraints. However, we can only approximate these concepts on the basis of available data. Using a (generalized) rough set approach [46.14] one can assume that an inclusion measure ν_p for $p \in [0, 1]$ is given making it possible to estimate the degree of inclusion of data patterns Pat , Pat_1 , and Pat_2 from languages L , L_1 , and L_2 in the concepts C , C_1 , and C_2 , respectively. Patterns included to a satisfactory degree p in a concept are classified as belonging to its lower approximation while those included to a degree less than a preset threshold $q \leq p$ are classified as belonging to its complement. Information granule decomposition supported by background knowledge is accomplished by searching for patterns Pat of *high* quality (e.g., supported by a large number of objects) and included in a satisfactory degree in the target concept C . These patterns are obtained by performing a given operation f on some input patterns Pat_1 and Pat_2 (from languages L_1 and L_2 , respectively) sufficiently included in C_1 and C_2 , respectively.

One can develop a searching method for such patterns Pat based on tuning of inclusion degrees p_1 , p_2 of input patterns Pat_1 , Pat_2 in C_1 , C_2 , respectively, to obtain patterns Pat (constructed from Pat_1 , Pat_2 by means of a given operation f) included in C in a satisfactory degree p and of acceptable quality (e.g., supported by the number of objects larger than a given threshold).

Assume degrees p_1, p_2 are given. There are two basic steps of searching procedures for relevant pairs of patterns (Pat_1, Pat_2) : (i) searching in languages L_1 and L_2 for sets of patterns included in degree at least p_1 and p_2 in concepts C_1 and C_2 , respectively, (ii) selecting from sets of patterns generated in step (i) satisfactory pairs of patterns.

We would like to add some general remarks on the above steps.

One can see that our method is based on a decomposition of degree p into degrees p_1 and p_2 under some constraints. In Step 2, we search for a relevant constraint relation R between patterns. By $Sem(Pat)$ we denote the meaning of Pat in, e.g., a given information system. The goal is to extract the following approximate rule of reasoning:

if

$$R(Sem(Pat_1), Sem(Pat_2)) \wedge \nu_{p_1}(Sem(Pat_1), C_1) \wedge \nu_{p_2}(Sem(Pat_2), C_2)$$

then

$$\nu_p(f(Sem(Pat_1) \times Sem(Pat_2)), C) \wedge Quality_t(f(Sem(Pat_1) \times Sem(Pat_2)))$$

where p is a given inclusion degree, t - a threshold of pattern quality measure $Quality_t$, f - operation on objects (patterns), Pat - target pattern, C, C_1, C_2 -given concepts, R, p_1, p_2 are expected to be extracted from data

and (Pat_1, Pat_2) is satisfying R (in the case we consider R is represented by a finite set of pattern pairs).

One can also consider soft constraint relations R_r where $r \in [0, 1]$ is a degree of truth to which the constraint relation holds.

Two sets P_1, P_2 are returned as the result of the first step. They consist of pairs $(pattern, degree)$ where $pattern$ is included in C_1, C_2 , respectively in degree at least $degree$.

These two sets are used to learn the relevant relation R . We outline two methods.

The first method is based on an experimental decision table (U, A, d) [46.6] where U is a set of pairs of discovered patterns in the first step; $A = \{deg_1, deg_2\}$ consists of two attributes such that $deg_i((Pat_1, Pat_2))$ is equal to the degree to which Pat_i is at least included in C_i for $i = 1, 2$; the decision d has value p to which the granule composed by means of operation f from (Pat_1, Pat_2) is at least included in C . From this decision table the decision rules of a special form are induced: **if** $deg_1 \geq p_1 \wedge deg_2 \geq p_2$ **then** $d \geq p$ where (p_1, p_2) is a minimal degree pair such that if $p'_1 \geq p_1$ and $p'_2 \geq p_2$ then the decision rule obtained from the above rule by replacing p'_1, p'_2 instead of p_1, p_2 , respectively, is also true in the considered decision table.

A version of such a method has been proposed in [46.9]. The relation R consists of the set of all pairs (Pat_1, Pat_2) of patterns with components included in C_1, C_2 , respectively in degrees $p'_1 \geq p_1, p'_2 \geq p_2$ where p_1, p_2 appear on the left hand side of some of the generated decision rules.

The second method is based on another experimental decision table (U, A, d) where objects are triplets $(x, y, f(x, y))$ composed out of objects x, y and the result of f on arguments x, y ; attributes from A describe features of arguments of objects and the decision d is equal to the degree to which the elementary granule corresponding to the description of $f(x, y)$ by means of attributes is at least included in C . This table is extended by adding new features being characteristic functions a_{Pat_i} of patterns Pat_i discovered in the first step. Next the attributes from A are deleted and from the resulting decision table the decision rules of a special form are induced: **if** $a_{Pat_1} = 1 \wedge a_{Pat_2} = 1$ **then** $d \geq p$ where if Pat_1, Pat_2 are included in C_1, C_2 , in degree at least p_1, p_2 , respectively and Pat'_1, Pat'_2 are included in C_1, C_2 in degree $p'_1 \geq p_1$ and $p'_2 \geq p_2$, respectively then a decision rule obtained from the above rule by replacing Pat'_1, Pat'_2 instead of Pat_1, Pat_2 is also true in the considered decision system. The decision rules describe constraints specifying the constraint relation R . Certainly, in searching procedures one should also consider constraints for the pattern quality.

The searching methods discussed in this section return local granule decomposition schemes. These local schemes can be composed using techniques discussed in [46.10]. The received schemes of granule construction (which can be also treated as approximate reasoning schemes) have also the following

stability (robustness) property: if the input granules are sufficiently close to input concepts then the output granule is sufficiently included in the target concept provided this property is preserved locally [46.10].

Conclusions

We have discussed methods for decomposition of information granules as a way to extract from data productions used to derive *AR*-schemes. Searching for relevant patterns for information granule decomposition can be based on methods for tuning parameters of rough set approximations of fuzzy cuts or concepts defined by differences between cuts [46.13], [46.16], i.e., by using so called rough-fuzzy granules. In this case, pattern languages consist of parameterized expressions describing the rough set approximations of *parts* of fuzzy concepts being fuzzy cuts or differences between cuts. Hence, an interesting research direction related to the development of new hybrid rough-fuzzy methods arises aiming at developing algorithmic methods for rough set approximations of such parts of fuzzy sets relevant for information granule decomposition.

In our further study we plan to implement the proposed strategies and test them on mentioned above real life data. This will require: (i) to develop ontologies for considered applications, (ii) further development of methods for extracting productions from data on the basis of decomposition, and (iii) synthesis methods for *AR*-schemes from productions. These methods will make it possible to reason by means of sensor measurements *along* inference schemes over ontologies (i.e., inference schemes over some standards) by means of attached to them *AR*-schemes discovered from background knowledge (including ontologies) and experimental data.

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47. Classification Models Based on Approximate Bayesian Networks

Dominik Ślęzak

Polish-Japanese Institute of Information Technology
Koszykowa 86, 02-008 Warsaw, Poland
slezak@pjwstk.waw.pl

Approximate Bayesian networks are applied to construction of the new case classification schemes. Main topics of their extraction from empirical data are discussed.

47.1 Introduction

A Bayesian network (BN) is a directed acyclic graph (DAG) designed to represent knowledge about probabilistic conditional independence statements between features ([47.4]). One can model data by extraction of approximate BNs with possibly low number of edges, but still approximately preserving information entropy of data (cf. [47.9]). This idea agrees with a common principle of tending to possibly short descriptions of models, what is assumed to provide the best knowledge generalization abilities ([47.2, 47.5, 47.6, 47.7]).

We show how methodology based on approximate Bayesian networks can be applied to the new case classification problem. We introduce the Bayesian-like decision model, which classifies new cases along the structure of BN with decision attribute as a root.

47.2 Frequencies in Data

It is assumed that data can be represented as an information system $\mathbf{A} = (U, A)$, where each attribute $a \in A$ is identified with function $a : U \rightarrow V_a$, for V_a denoting the set of values on a . Let us write $A = \langle a_1, \dots, a_n \rangle$ according to some ordering over the set of attributes. For any $B \subseteq A$, function $B : U \rightarrow V_B^U$ labels objects $u \in U$ with vectors $B(u) = \langle a_{i_1}(u), \dots, a_{i_m}(u) \rangle$, where values of successive attributes $a_{i_j} \in B$, $j = 1, \dots, m$. The set $V_B^U = \{B(u) : u \in U\}$ gathers all vectors of values on B , which occur in \mathbf{A} .

Reasoning about data can be stated, e.g., as the classification problem concerning a distinguished decision to be predicted under information provided over the rest of attributes. For this purpose, one represents data as a decision table $\mathbf{A} = (U, A \cup \{d\})$, $d \notin A$. To express conditions \rightarrow decision dependencies, one can use frequencies of occurrence of $v_d \in V_d$ conditioned by $w_B \in V_B^U$, of the form

$$P_{\mathbf{A}}(v_d/w_B) = \frac{|\{u \in U : B(u) = w_B \wedge d(u) = v_d\}|}{|\{u \in U : B(u) = w_B\}|} \tag{47.1}$$

Then, for a given $\alpha \in [0, 1]$, α -inexact decision rule $B = w_B \Rightarrow_{\alpha} d = v_d$ is satisfied, iff $P_{\mathbf{A}}(v_d/w_B) \geq \alpha$, i.e., iff for at least $\alpha \cdot 100\%$ of objects $u \in U$ such that $B(u) = w_B$ we have also $d(u) = v_d$. The strength of the rule is provided by quantity $P_{\mathbf{A}}(w_B) = |\{u \in U : B(u) = w_B\}| / |U|$. It corresponds to the chance that an object $u \in U$ will be recognized, i.e., it will satisfy the left side of the rule.

Frequencies were introduced to rough sets as rough membership functions ([47.3]). The rough set principle of reduction of possibly large amount of redundant information takes in their context the following form:

Definition 47.2.1. *Given $\mathbf{A} = (U, A \cup \{d\})$, we say that $B \subseteq A$ preserves frequency of d iff for each $u \in U$ we have $P_{\mathbf{A}}(d(u)/B(u)) = P_{\mathbf{A}}(d(u)/A(u))$. If, additionally, there is no proper subset of B satisfying such a condition, then B is called a frequency decision reduct.*

Several alternative definitions of a frequency-based reduct were proposed within the rough set framework (cf. [47.5, 47.6]). One can mention about the following aspects of adaptation of frequencies to the rough set methodology:

Remark 47.2.1. If we treat $P_{\mathbf{A}}$ as the empirical probability for the product space over the set of random variables $A \cup \{d\}$, then preserving frequency of d by B means that d is independent on $A \setminus B$ conditioned by B . So, each frequency decision reduct is actually a Markov boundary of d within A ([47.4]).

Remark 47.2.2. Frequency distribution provides the basis for expressing inexact dependencies in various ways. For instance, the set approximations or generalized decision functions developed directly within rough sets ([47.2]) can be derived from $P_{\mathbf{A}}$ (cf. [47.8]).

47.3 Approximate Independence

Condition for preserving frequency turns out to be too rigorous with respect to possible noises or fluctuations in real life data. This is the general problem of dealing with probabilistic conditional independence (PCI) while analyzing empirical data. In [47.9] the information entropy-based approximation of PCI was proposed.

Definition 47.3.1. *Let $\mathbf{A} = (U, A)$ and $X, Y \subseteq A$ be given. Entropy of X conditioned by Y is defined by*

$$H_{\mathbf{A}}(X/Y) = -\frac{1}{|U|} \sum_{u \in U} \log_2 P_{\mathbf{A}}(X(u)/Y(u)) \tag{47.2}$$

Definition 47.3.2. For $\varepsilon \in [0, 1)$, $\mathbf{A} = (U, A)$, $X, Y, Z \subseteq A$, we say that X is ε -approximately independent on Z conditioned by Y (we will denote such a fact by $I_{\mathbf{A}}^{\varepsilon}(X/Y/Z)$), iff

$$H_{\mathbf{A}}(X/Y) + \log_2(1 - \varepsilon) \leq H_{\mathbf{A}}(X/Y \cup Z) \quad (47.3)$$

If \mathbf{A} takes the form of $\mathbf{A} = (U, A \cup \{d\})$, we say that $B \subseteq A$ ε -approximately preserves frequency of d , iff $I_{\mathbf{A}}^{\varepsilon}(d/B/A \setminus B)$ holds. If, additionally, there is no proper subset of B satisfying such a condition, then B is called an ε -approximate frequency decision reduct.

Proposition 47.3.1. The notions of a frequency decision reduct and a 0-approximate frequency decision reduct are equivalent.

According to Remark 47.2.1, ε -approximate frequency decision reducts can be treated as ε -approximate Markov boundaries of d . By tuning $\varepsilon \in [0, 1)$, we can search for smaller boundaries " ε -almost" preserving entropy-based information about decision.

Theorem 47.3.1. Let $\varepsilon \in [0, 1)$ be given. The problem of finding minimal ε -approximate frequency decision reduct is NP-hard.

One can deal with the above problem by adaptation of techniques developed in [47.5, 47.6], devoted to searching for decision reducts of various types.

47.4 Bayesian Classification

One of the aims of searching for approximate reducts is to improve the ability of classification of new cases. Any $B \subseteq A$ corresponds to the bunch of possibly inexact rules $B = B(u) \Rightarrow_{P_{\mathbf{A}}(d(u)/B(u))} d = d(u)$ indexed by successive objects $u \in U$. If B is an ε -approximate frequency decision reduct, then elements of the above bunch imply particular decision classes in a way " ε -close" to decision rules based on the whole A . If B is substantially smaller than A , then the rules generated by B are shorter and stronger. Thus, they usually recognize new cases more effectively.

The classification process can also correspond to the rules with decision situated at their left sides. This is the case for the Bayesian methods (cf. [47.1, 47.4, 47.7]). A new case with values equal to those of some object $u \in U$ can be classified as, e.g., having decision value $v = \arg \max_{v_d \in V_d} P_{\mathbf{A}}(A(u)/v_d)$, i.e. the value on d for which the observed vector on A occurs the most frequently in \mathbf{A} . To improve the ability of the new case recognition, one can set up an ordering $A = \langle a_1, \dots, a_n \rangle$ and note that

$$P_{\mathbf{A}}(A(u)/d(u)) = \prod_{i=1}^n P_{\mathbf{A}}(a_i(u)/d(u), a_1(u), \dots, a_{i-1}(u)) \quad (47.4)$$

Proposition 47.4.1. *Let $\mathbf{A} = (U, A \cup \{d\})$ with ordering $A = \langle a_1, \dots, a_n \rangle$ be given. Assume that for each $i = 1, \dots, n$, a frequency decision reduct B_i for table $\mathbf{A}_i = (U, \{d, a_1, \dots, a_{i-1}\} \cup \{a_i\})$ is provided. For each $u \in U$, we have*

$$\arg \max_{v_d \in V_d} P_{\mathbf{A}}(A(u)/v_d) = \arg \max_{v_d \in V_d} \prod_{i: d \in B_i} P_{\mathbf{A}}(a_i(u)/v_d, B_i \setminus \{d\}(u)) \quad (47.5)$$

According to the above equality, there is no need to consider probabilities corresponding to subsets B_i not including d , since they are independent on the choice of decision value. We thus obtain a new formula for the new case classification, which is comparable to the previous one over vectors occurring in data. In case of combinations not included in V_A^U , it remains to trust into the generalization abilities of the classification scheme based on the right side of (47.5). Obviously, these abilities could be still improved by considering subsets B_i as approximate decision reducts. Then, however, one must remember that outcomes of classification based on the right side of (47.5) would be just " ε -close" to those obtained by application of the left one.

47.5 Approximate Bayesian Networks

The ordered frequency models turn out to be closely related to the notion of a Bayesian network ([47.4]) – a tool for the graphical representation of knowledge about probabilistic independence statements, by using the structure of a directed acyclic graph (DAG). In its approximate form, the notion of a Bayesian network can be defined as follows:

Definition 47.5.1. *For given ε and $\mathbf{A} = (U, A)$, DAG $D = (A, \vec{E})$ is called an ε -approximate Bayesian network (an ε -BN, in short), iff*

$$\forall_{X, Y, Z \subseteq A} [\langle X/Y/Z \rangle_D \Rightarrow I_{\mathbf{A}}^{\varepsilon}(X/Y/Z)] \quad (47.6)$$

where by $\langle X/Y/Z \rangle_D$ we mean that X is d -separated from Z by Y , i.e., that any path between any elements of X and Z comes through (1) a serial or diverging connection covered by some node in Y , or (2) a converging connection not in Y , with no directed path towards any node in Y .

Theorem 47.5.1. *Given ε , $\mathbf{A} = (U, A)$ and DAG $D = (A, \vec{E})$, let us define the entropy of D by*

$$H_{\mathbf{A}}(\vec{E}) = \sum_{a \in A} H_{\mathbf{A}}(a/\{b \in A : \langle b, a \rangle \in \vec{E}\}) \quad (47.7)$$

If inequality $H_{\mathbf{A}}(\vec{E}) + \log_2(1 - \varepsilon) \leq H_{\mathbf{A}}(A)$ holds, then D is an ε -BN for \mathbf{A} .

One can consider Bayesian nets for decision tables as well. Actually, the construction of the product at the right side of (47.5), based on reducts calculated along a given ordering, corresponds to the structure of BN over $A \cup \{d\}$, with the root in d . Theorem 47.5.1, applied to decision tables, results with a conclusion that similar classification schemes may be worth considering also as based on approximate reducts.

Definition 47.5.2. Let ϵ and $\mathbf{A} = (U, A \cup \{d\})$, $A = \langle a_1, \dots, a_n \rangle$, be given. We say that $\mathcal{B} = \langle B_1, \dots, B_n \rangle$ is an ϵ -approximate ordered frequency model for \mathbf{A} , iff there are thresholds $\varepsilon_1, \dots, \varepsilon_n \in [0, 1)$ satisfying inequality $(1 - \varepsilon_1) \cdot \dots \cdot (1 - \varepsilon_n) \geq 1 - \epsilon$, such that B_i is an ε_i -approximate frequency decision reduct for $\mathbf{A}_i = (U, \{d, a_1, \dots, a_{i-1}\} \cup \{a_i\})$, for each $i = 1, \dots, n$.

Proposition 47.5.1. Let ϵ and $\mathbf{A} = (U, A \cup \{d\})$ be given. Any ϵ -approximate ordered frequency model $\mathcal{B} = \langle B_1, \dots, B_n \rangle$ induces the ϵ -BN $D = (A \cup \{d\}, \vec{E})$ defined by putting $\vec{E} = \bigcup_{i=1}^n \{ \langle b, a_i \rangle : b \in B_i \}$.

47.6 Conclusions

We presented the Bayesian-like classification model based on approximate frequency decision reducts, extracted from training data with respect to an ordering over conditional attributes. It turned out to have much in common with modeling data with approximate Bayesian networks introduced in [47.9]. We believe that presented methodology will provide new possibilities of application of Bayesian networks to the real life data analysis.

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48. Identifying Adaptable Components – A Rough Sets Style Approach

Yoshiyuki Shinkawa¹ and Masao J. Matsumoto²

¹ IBM Japan, Ltd, Systems Laboratory ,
1-1, Nakase, Mihama-ku, Chiba-shi, Chiba Japan
yshink@jp.ibm.com

² The University of Tsukuba, Graduate School of Systems Management,
3-29-1, Otsuka, Bunkyo-ku, Tokyo Japan

This paper presents a formal approach to identifying partial adaptability of software components. First we discuss the partial adaptability of components with the same arity (or interface) as a requirement. Then we extend the approach to the components with the different arities. Rough Set Theory (RST)-like method is used to identify algebraic equivalency between the components and the requirements, on which the adaptability is based.

48.1 Introduction

Component based development imposes several new difficulties on us, in spite of many advantages. One of the critical difficulties is that there are no appropriate ways to identify adaptable components, since there are no comprehensive measures to evaluate the adaptation of software components.

While the most previous component based approaches focused on full adaptability of the components, this paper discusses partial adaptability and component collaboration.

48.2 Defining Adaptation of Software Components

There are many aspects in the requirements to software, however most essential and imperative one is functional adaptation, which implies each software component performs desired data transformation [48.5]. Since requirements and software components deal with many types of data in order to define functionality of them, the above transformation rules are expressed in the form of S -sorted functions which compose (many-sorted) Σ algebra [48.1].

Σ algebra provides an interpretation for the signature $\Sigma = (S, \Omega)$, where S is a set of sorts, and Ω is an $S^* \times S$ sorted set of operation names. S^* is the set of finite sequences of elements of S . A Σ algebra is an algebra (A, F) , where

1. $A = \{A_\sigma | \sigma \in S\}$ (a set of carriers) and
2. $F = \{f_A | f \in \Omega_{\sigma_1 \dots \sigma_n, \sigma}\} \quad f_A : A_{\sigma_1} \times \dots \times A_{\sigma_n} \rightarrow A_\sigma.$

S-sorted function f_A is said to have arity $\sigma_1 \dots \sigma_n$ and result sort σ .

Operational equivalency between two Σ algebras \mathcal{A} and \mathcal{B} is evaluated by Σ homomorphism, which is defined as a family of functions $\eta = \{\eta_\sigma | \sigma \in S, \eta_\sigma : A_\sigma \rightarrow B_\sigma\}$ such that

$$\forall f \in \Omega_{\sigma_1 \dots \sigma_n, \sigma}, \forall a_i \in A_{\sigma_i} [\eta_\sigma(f_A(a_1, \dots, a_n)) = f_B(\eta_{\sigma_1}(a_1), \dots, \eta_{\sigma_n}(a_n))]$$

where $\mathcal{A}=(A, F)$ and $\mathcal{B}=(B, G)$ are Σ algebras. f_A and f_B are the functions in F and G respectively, or elements of A and B if $n = 0$. Each requirement compose a Σ algebra including only one function, and so does each component. If the domain of definition in such function is finite, or countable, each function can be represented in the form of a decision table [48.4].

Assuming a requirement and a component

$$\begin{aligned} f_{\sigma_1 \dots \sigma_n, \sigma} &: \mathbb{D} (\subseteq A_{\sigma_1} \times \dots \times A_{\sigma_n}) \longrightarrow A_\sigma \\ g_{\sigma_1 \dots \sigma_n, \sigma} &: \mathbb{E} (\subseteq B_{\sigma_1} \times \dots \times B_{\sigma_n}) \longrightarrow B_\sigma \end{aligned}$$

are given, those functions f and g are represented by decision tables as shown in Table 48.2. In those tables i th row or k th row of the table f or g means $f(u_{i1}, \dots, u_{in}) = v_i$ or $g(x_{k1}, \dots, x_{kn}) = y_k$ respectively.

Table 48.1. A decision table of the requirement f and the component g

The table of f				The table of g			
$U^{(r)}$	$A_{\sigma_1} \dots A_{\sigma_j} \dots A_{\sigma_n}$	A_σ		$U^{(c)}$	$B_{\sigma_1} \dots B_{\sigma_j} \dots B_{\sigma_n}$	B_σ	
1	$u_{11} \dots u_{1j} \dots u_{1n}$	v_1		1	$x_{11} \dots x_{1j} \dots x_{1n}$	y_1	
\vdots	\vdots	\vdots		\vdots	\vdots	\vdots	
i	$u_{i1} \dots u_{ij} \dots u_{in}$	v_i		k	$x_{k1} \dots x_{kj} \dots x_{kn}$	y_k	
\vdots	\vdots	\vdots		\vdots	\vdots	\vdots	

48.3 Identifying One-to-One Component Adaptation

When a requirement is expressed in the form of S-sorted function with the arity $\sigma_1 \dots \sigma_n$ and the result sort σ , the adaptable components to it must have the same arity and result sort, if the adaptation is evaluated by Σ homomorphism. The carriers A_{σ_j} and B_{σ_j} can be regarded as *attributes* which can classify $U^{(r)}$ and $U^{(c)}$ by them [48.3].

In order to identify Σ homomorphism from the requirement to the component, we examine all the possible sets of mappings

$$\{\eta_{\sigma_j} : A_{\sigma_j} \longrightarrow B_{\sigma_j}\} (j = 0, 1, \dots, n)$$

and there are the permutations $q_j P_{p_j}$ kinds of mappings as η_{σ_j} , if they are injections.

If $\{\eta_{\sigma_j}\}$ is Σ homomorphism, the formula

$$\forall i \in U^{(r)} \quad [g(\eta_{\sigma_1}(u_{i1}), \dots, \eta_{\sigma_n}(u_{in})) = \eta_{\sigma}(f(u_{i1}, \dots, u_{in}))] \quad (48.1)$$

holds. This formula is equivalent to the following formula

$$\forall i \in U^{(r)} \exists k \in U^{(c)} \quad [x_{kj} = \eta_{\sigma_j}(u_{ij}) \text{ and } y_k = \eta_{\sigma}(v_i)] \quad (48.2)$$

when f and g are expressed in the forms of Table 48.2, since they include all the possible data transformation by f and g respectively. The formula (48.2) implies that each row in Table f is mapped into a single row in Table g by Σ homomorphism $\{\eta_{\sigma_j}\}$. When the above Σ homomorphism does not exist, we have to reduce the requirement f in the following way in order to define Σ homomorphism for *partial adaptation*.

1. Let $\mathcal{E} = \{\{\eta_{\sigma_j} \mid j = 0, 1, \dots, n\}\}$ be a set of all the possible sets of mapping
 $\{\eta_{\sigma_j} : A_{\sigma_j} \longrightarrow B_{\sigma_j}\} (j = 0, 1, \dots, n)$ where $\eta_{\sigma_0} = \eta_{\sigma}$.
2. For each $\{\eta_{\sigma_j} \mid j = 0, 1, \dots, n\}$, classify $U^{(r)}$ for the requirement f into $U_A^{(r)}(\{\eta_{\sigma_j}\})$ and $U_N^{(r)}(\{\eta_{\sigma_j}\})$, where
 $U_A^{(r)}(\{\eta_{\sigma_j}\}) = \{i \mid \exists k \in U^{(c)} [\eta_{\sigma_j}(u_{ij}) = x_{kj}, \text{ and } \eta_{\sigma}(v_i) = y_k]\}$ and
 $U_N^{(r)}(\{\eta_{\sigma_j}\}) = U^{(r)} - U_A^{(r)}$
3. Select the set of mapping $\{\eta_{\sigma_j}^* \mid j = 0, 1, \dots, n\} \in \mathcal{E}$
 which makes the cardinality of $U_A^{(r)}$ maximum, that is,
 $\forall \{\eta_{\sigma_j}\} \in \mathcal{E} [card(U_A^{(r)}(\{\eta_{\sigma_j}^*\})) \geq card(U_A^{(r)}(\{\eta_{\sigma_j}\}))]$ holds.

$U_A^{(r)}(\{\eta_{\sigma_j}\})$ represents the maximum adaptation of the component g to the requirement f . We denote $U_A^{(r)}(\{\eta_{\sigma_j}\}) = U_A^{(r)}(g)$. By extracting the rows belonging to $U_A^{(r)}(g)$ from Table f , we can define the new function $f^* \subseteq f$.

The Σ algebra $\mathcal{B} = (B, G)$ is evidently Σ homomorphic to the Σ algebra $\mathcal{A}^* = (A^*, F^*)$, where $A^* = \{A_{\sigma_1}^*, \dots, A_{\sigma_n}^*, A_{\sigma}^*\}$, $F^* = \{f^*\}$, $A_{\sigma_j}^* = \{x_{ij} \mid i \in U_A^{(r)}\}$ and $A_{\sigma}^* = \{y_i \mid i \in U_A^{(r)}\}$. The function f^* is referred to as the *restriction* of f into A^* .

After examining all the functions in \mathcal{G} , that is, the set of S-sorted functions with the same arity and result sort as the requirement f , if

$$f = \bigcup_{g \in \mathcal{G}} f^*, \text{ or equivalently } U^{(r)} = \bigcup_{g \in \mathcal{G}} U_A^{(r)}(g)$$

holds, the requirement f is satisfiable by the set of the functions $\mathcal{G} = \{g\}$, using the set of Σ homomorphism $\mathcal{E}^* = \{\{\eta_{\sigma_j}^* \mid (j = 0, 1, \dots, n)\}\}$. When implementing the requirement f by the above set of components $\mathcal{G} = \{g\}$, we need the knowledge on which part of the function f (or the domain of definition of f) is satisfied by each component g . Obviously the less components require the less knowledge, and it is desirable from practical viewpoint.

Identifying the minimum set of components is a kind of *the set cover problem* with identical costs, and a near optimal solution can be found by *the greedy method* [48.2]. This method is expressed in the following way in our situation.

1. Select $g_1 \in \mathcal{G}$ which make $\text{card}(U_A^{(r)}(g_1))$ maximum. Denote this $U_A^{(r)}(g_1)$ as U_1^* .
2. Select $g_2 \in \mathcal{G}$ ($g_2 \neq g_1$) which make $\text{card}(U_A^{(r)}(g_2) \cap \overline{U_1^*})$ maximum, where \overline{U} means the complementary set of U . Denote this $U_A^{(r)}(g_2)$ as U_2^* .
3. Repeat the above procedure. Each time we identify $g_i \in \mathcal{G}$ which make $\text{card}(U_A^*(g_i) \cap (\bigcap_{k=1}^{i-1} \overline{U_k^*}))$ maximum.
4. Terminate the iteration if we identify $g_n \in \mathcal{G}$ which satisfies $U_n^* \cup \dots \cup U_1^* = U^{(r)}$

$\mathcal{G}^* = \{g_1, \dots, g_n\}$ is the minimum set of components that satisfies the requirement f .

48.4 Identifying One-to-Many Component Adaptation

Even though a requirement can not be satisfied by a set of components by the above way, there could be a possibility to satisfy it by collaboration of several components.

Assuming there is a pair of components $\langle g_1, g_2 \rangle$ for a requirement f , which satisfy

$$f_{\sigma_1 \dots \sigma_n, \sigma} : \mathbb{D} \longrightarrow A_\sigma \quad (\mathbb{D} \subseteq A_{\sigma_1} \times \dots \times A_{\sigma_n}) \quad (48.3)$$

$$g_{1\sigma_1 \dots \sigma_m, \rho} : \mathbb{E}_1 \longrightarrow B_\rho \quad (\mathbb{E}_1 \subseteq B_{\sigma_1} \times \dots \times B_{\sigma_m}) \quad (48.4)$$

$$g_{2\sigma_{m+1} \dots \sigma_n, \sigma} : \mathbb{E}_2 \longrightarrow B_\sigma \quad (\mathbb{E}_2 \subseteq B_{\sigma_{m+1}} \times \dots \times B_{\sigma_n}) \quad (48.5)$$

$$\exists m' \quad (m < m' \leq n) \quad [B_{\sigma_{m'}} = B_\rho] \quad (48.6)$$

Since the order of the sorts in the requirement f , that is the arity of f , is arbitrary and does not affect the data transformation rule of f , we can reorder the arity of f in order to satisfy the above conditions.

When g_1 and g_2 are represented in the form of decision tables, we can connect g_1 and g_2 in order to compose the new function with the same arity and result sort as f in the following way, supposing f is represented in the form of Table 48.2.

1. Let η_{σ_j} and η_σ be mappings $\eta_{\sigma_j} : A_{\sigma_j} \longrightarrow B_{\sigma_j}$ ($1 \geq j \geq n$) and $\eta_\sigma : A_\sigma \longrightarrow B_\sigma$
2. Connect two rows $\langle x_{k1}, \dots, x_{km} \rangle$ and $\langle x_{k',m+1}, \dots, x_{k'n} \rangle$, which satisfy $x_{kj} = \eta_{\sigma_j}(u_{ij})$ ($j = 1, \dots, m$), $x_{k'j'} = \eta_{\sigma_{j'}}(u_{ij'})$ ($j' = m+1, \dots, n$), and $y_j = x_{k'm'}$
3. Define the new decision table which is composed of the rows $\langle x_{k1}, \dots, x_{km}, x_{k',m+1}, \dots, x_{k'n}, z_{k'} \rangle$

There are multiple $\{\eta_{\sigma_j}\}$ as discussed in the previous section, therefore there could be multiple decision tables composed through the above way. We denote the table with maximum number of rows as g^* , which represents a new S-sorted function.

We obtain a subset of f corresponding to g^* , which is derived from Table f by extracting the rows indexed by i selected in the step 2 in the above procedure. We denote this subset as f^* . The g^* is Σ homomorphic to the f^* as we discussed in Section 48.3.

By examining all the possible pair of the above g_1 and g_2 , we can identify the set of Σ homomorphic function pairs $\{\langle f^*, g^* \rangle\}$. If

$$\bigcup_{\langle g_1, g_2 \rangle} f^* = f$$

holds, the requirement f can be satisfied by the set of S-sorted functions $\{\langle g_1, g_2 \rangle\}$. We can identify the minimum set of the above pair $\{\langle g_1, g_2 \rangle\}$ in the similar way to Section 48.3. This approach can be extend to the S-sorted function tuple $\langle g_1, \dots, g_l \rangle$ similarly.

48.5 Conclusions

A formal approach to identifying adaptable software components to requirements is proposed in this paper. The adaptation is evaluated by Σ homomorphism between the requirements and the components. Unlike the previous approaches, we define partial adaptation based on decision tables which represent the requirements and the components. We also defined two forms of adaptation, that is, one-to-one adaptation and one-to-many adaptation.

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49. Rough Measures and Integrals: A Brief Introduction

Zdzisław Pawlak¹, James F. Peters², Andrzej Skowron³, Z. Suraj⁴,
S. Ramanna², and M. Borkowski²

¹ Polish Academy of Sciences, Bałtycka 5, 44-000 Gliwice, Poland

² Computer Engineering, Univ. of Manitoba, Winnipeg,
MB R3T 5V6 Canada

³ Institute of Mathematics, Warsaw Univ., Banacha 2,
02-097 Warsaw, Poland

⁴ Univ. of Information Technology and Management, H. Sucharskiego 2,
35-225 Rzeszów, Poland

This paper introduces a measure defined in the context of rough sets. Rough set theory provides a variety of set functions that can be studied relative to various measure spaces. In particular, the rough membership function is considered. The particular rough membership function given in this paper is a non-negative set function that is additive. It is an example of a rough measure. The idea of a rough integral is revisited in the context of the discrete Choquet integral that is defined relative to a rough measure. This rough integral computes a form of ordered, weighted "average" of the values of a measurable function. Rough integrals are useful in culling from a collection of active sensors those sensors with the greatest relevance in a problem-solving effort such as classification of a "perceived" phenomenon in the environment of an agent.

49.1 Introduction

This paper introduces a measure defined in the context of rough sets [49.3]. In this paper, we investigate measures defined on a family $\wp(X)$ of all subsets of a finite set X , i.e. on the powerset of X . A fundamental paradigm in rough set theory is set approximation. Hence, there is interest in discovering a family of measures useful in set approximation. By way of practical application, an approach to fusion of homogeneous sensors deemed relevant in a classification effort is considered (see, e.g., [49.6]). Application of rough integrals has also been considered recently relative to sensor signal classification by intelligent agents [49.8] and by web agents [49.9]. This research also has significance in the context of granular computing [49.10].

This paper is organized as follows. Section 49.2 presents a brief introduction to classical additive set functions. Basic concepts of rough set theory are presented in Section 49.3. The discrete Choquet integral is defined relative to a rough measure in Section 49.4. A brief introduction to sensor relevance is given in Section 49.5.

49.2 Classical Additive Set Functions

This section gives a brief introduction to one form of additive set functions in measure theory. Let $\text{card}(X)$ denote the cardinality of a finite set X (i.e., the number of elements of set X).

Definition 49.2.1. Let X be a finite, non-empty set. A function $\lambda : \wp(X) \rightarrow \mathfrak{R}$ where \mathfrak{R} is the set of all real numbers is called a *set function* on X .

Definition 49.2.2. Let X be a finite, non-empty set and let λ be a set function on X . The function λ is said to be *additive* on X iff $\lambda(A \cup B) = \lambda(A) + \lambda(B)$ for every $A, B \in \wp(X)$ such that $A \cap B = \emptyset$ (i.e., A and B are disjoint subsets of X).

Definition 49.2.3. Let X be a finite, non-empty set and let λ be a set function on X . A function λ is called to be *non-negative* on X iff $\lambda(Y) \geq 0$ for any $Y \in \wp(X)$.

Definition 49.2.4. Let X be a set and let λ be a set function on X . A function λ is called to be *monotonic* on X iff $A \subseteq B$ implies that $\lambda(A) \leq \lambda(B)$ for every $A, B \in \wp(X)$.

A brief introduction to the basic concepts in rough set theory (including the introduction of an additive rough measure) is briefly given in this section.

49.3 Basic Concepts of Rough Sets

Rough set theory offers a systematic approach to set approximation [49.2]. To begin, let $S = (U, A)$ be an information system where U is a non-empty, finite set of objects and A is a non-empty, finite set of attributes, where $a : U \rightarrow V_a$ for every $a \in A$. For each $B \subseteq A$, there is associated an equivalence relation $\text{Ind}_A(B)$ such that

$$\text{Ind}_A(B) = \{(x, x') \in U^2 \mid \forall a \in B. a(x) = a(x')\}$$

If $(x, x') \in \text{Ind}_A(B)$, we say that objects x and x' are indiscernible from each other relative to attributes from B . The notation $[x]_B$ denotes equivalence classes of $\text{Ind}_A(B)$.

Definition 49.3.1. Let $S = (U, A)$ be an information system, $B \subseteq A$, $u \in U$ and let $[u]_B$ be an equivalence class of an object $u \in U$ of $\text{Ind}_A(B)$. The set function

$$\mu_u^B : \wp(U) \rightarrow [0, 1], \text{ where } \mu_u^B(X) = \frac{\text{card}(X \cap [u]_B)}{\text{card}([u]_B)} \quad (49.1)$$

for any $X \in \wp(U)$ is called a *rough membership function (rmf)*.

The form of rough membership function in Def. 49.3.1 is slightly different from the classical definition where the argument of the rough membership function is an object x and the set X is fixed [49.3].

Definition 49.3.2. Let $u \in U$. A non-negative and additive set function $\rho_u : \wp(X) \rightarrow [0, \infty)$ defined by $\rho_u(Y) = \rho'(Y \cap [u]_B)$ for $Y \in \wp(X)$, where $\rho' : \wp(X) \rightarrow [0, \infty)$ is called a *rough measure* relative to $U/Ind_A(B)$ and u on the indiscernibility space $(X, \wp(X), U/Ind_A(B))$.

The rough membership function $\mu_u^B : \wp(X) \rightarrow [0, 1]$ is a non-negative set function [49.4].

Proposition 49.3.1. (Pawlak et al. [49.4]) The rough membership function μ_u^B as defined in Definition 49.3.1 (formula (49.1)) is additive on U .

Proposition 49.3.2. $(X, \wp(X), U/Ind_A(B), \{\mu_u^B\}_{u \in U})$ is a rough measure space over X and B .

Other rough measures based on upper {lower} approximations are possible but consideration of these other measures is outside the scope of this paper.

49.4 Rough Integrals

Rough integrals of discrete functions were introduced in [49.5]. In this section, we consider a variation of the Lebesgue integral, the discrete Choquet integral defined relative to a rough measure. In what follows, let $X = \{x_1, \dots, x_n\}$ be a finite, non-empty set with n elements. The elements of X are indexed from 1 to n . The notation $X_{(i)}$ denotes the set $\{x_{(i)}, x_{(i+1)}, \dots, x_{(n)}\}$ where $i \geq 1$ and $n = card(X)$. The subscript (i) is called a permutation index because the indices on elements of $X_{(i)}$ are chosen after a reordering of the elements of X . This reordering is "induced" by an external mechanism.

Definition 49.4.1. Let ρ be a rough measure on X where the elements of X are denoted by x_1, \dots, x_n . The discrete Choquet integral of $f : X \rightarrow \mathfrak{R}^+$ with respect to the rough measure ρ is defined by

$$\int f d\rho = \sum_{i=1}^n (f(x_{(i)}) - f(x_{(i-1)}))\rho(X_{(i)})$$

where $\bullet_{(i)}$ specifies that indices have been permuted so that $0 \leq f(x_{(i)}) \leq \dots \leq f(x_{(n)})$, $X_{(i)} := \{x_{(i)}, \dots, x_{(n)}\}$, and $f(x_{(0)}) = 0$.

This definition of the Choquet integral is based on a formulation in Grabisch [49.1], and applied in [49.2], [49.7]. The rough measure $\rho(X_{(i)})$ value serves as a "weight" of a coalition (or combination) of objects in set $X_{(i)}$ relative to $f(x_{(i)})$. It should be observed that in general the Choquet integral has the effect of "averaging" the values of a measurable function. This averaging closely resembles the well-known Ordered Weighted Average (OWA) operator [49.11].

Proposition 49.4.1. Let $0 < s \leq r$. If $a(x) \in [s, r]$ for all $x \in X_a$, then $\int a d\mu_u^e \in (0, r]$ where $u \in U$.

49.5 Relevance of a Sensor

In this section, we briefly consider the measurement of the relevance of a sensor using a rough integral. A sensor is considered relevant in a classification effort in the case where $\int a d\mu_u^e$ for a sensor a is close enough to some threshold in a target interval of sensor values. Assume that a denotes a sensor that responds to stimuli with measurements that govern the actions of an agent. Let $\{a\} = B \subseteq A$ where $a : U \rightarrow [0, 0.5]$ where each sample sensor value $a(x)$ is rounded to two decimal places. Let $(Y, U - Y)$ be a partition defined by an expert and let $[u]_e$ denote a set in this partition containing u for a selected $u \in U$. We further assume the elements of $[u]_e$ are selected relative to an interval $(u - \varepsilon, u + \varepsilon)$ for a selected $\varepsilon \geq 0$. We assume a decision system (X_a, a, e) is given for any considered sensor a such that $X_a \subseteq U$, $a : X_a \rightarrow \mathfrak{R}^+$ and e is an expert decision restricted to X_a defining a partition $(Y \cap X_a, (U - Y) \cap X_a)$ of X_a . Moreover, we assume that $X_a \cap [u]_e \neq \emptyset$. The set $[u]_e$ is used to classify sensors and is given the name "classifier". Let \bar{u} denote the average value in the classifier $[u]_e$, and let $\delta \in [0, 1]$. Then, for example, the selection R of the most relevant sensors in a set of sensors is found using

$$R = \left\{ a_i \in B : \left| \int a_i d\mu_u^e - a(\bar{u}) \right| \leq \delta \right\}$$

In effect, the integral $\int a_i d\mu_u^e$ serves as a filter inasmuch as it "filters" out all sensors with integral values not close enough to $a(\bar{u})$.

49.6 Conclusion

Rough set theory provides a variety of set functions that can be studied relative to various measure spaces. In particular, the rough membership function is considered. The particular rough membership function given in this paper is a non-negative set function which is additive and, hence, is an example of a rough measure. We are interested in identifying those sensors considered relevant in a problem-solving effort. The rough integral introduced in this paper serves as a means of distinguishing relevant and non-relevant sensors in a classification effort.

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50. Association Rules in Semantically Rich Relations: Granular Computing Approach

T.Y. Lin¹ and Eric Louie²

¹ Department of Mathematics and Computer Science
San Jose State University, San Jose, California 95192-0103
tylin@cs.sjsu.edu

² IBM Almaden Research Center
650 Harry Road, San Jose, CA 95120
ewlouie@almaden.ibm.com

In "real world" databases, attribute domains are more than Cantor sets; the additional semantics defined, in this paper, is assumed to be carried by a binary relation. Association rules in such databases are investigated. In this paper, we show that the cost of checking the additional semantics is rather small. Some experiments are reported.

50.1 Introduction

In relation theory, all attribute domains are assumed to be Cantor sets. However, in practice, they are "real world sets," that is, there are interactions among themselves. The question is: Can such interactions be modeled mathematically? In first order logic, the real world is modeled by a Cantor set with relational structure. We follow this approach; as a first step we consider simplest case, that is, the relational structure is defined by a binary relation. Such "real world sets;" have been called binary neighborhood system spaces, or BNS-spaces [50.4], [50.3].

This paper reports the study of association rules in such semantically rich relations.

50.2 Relational Models and Rough Granular Structures

A relation is a knowledge representation that maps each entity to a tuple of attribute values. Table 50.1 illustrates the knowledge representation of the universe $V = \{v_1, v_2, v_3, v_4, v_5\}$.

In this view, an attribute can be regarded as a projection that maps entities to attribute values, for example in Table 50.1, the CITY attribute is the map,

$$f : V \longrightarrow \text{Dom}(\text{CITY}),$$

which assigns, at every tuple, the element in the first column to the element in the last column. The family of complete inverse image $f^{-1}(y)$ forms a

partition (equivalence relation). So each column (attribute) defines an equivalence relation. So Table 50.1 gives rise to 4 named equivalence relations. Pawlak called the pair V and a finite family of equivalence relations a knowledge base. Since knowledge bases often have different meaning, we will call it rough granular structure, or rough structure, which is a special form of binary granular structure [50.3].

Table 50.1. Information Table of Suppliers; arrows and parentheses will be suppressed

V		$(S\#$	SNAME	Status	City)
v_1	\rightarrow	$(S_1$	Smith	TWENTY	$C_1)$
v_2	\rightarrow	$(S_2$	Jones	TEN	$C_2)$
v_3	\rightarrow	$(S_3$	Blake	TEN	$C_2)$
v_4	\rightarrow	$(S_4$	Clark	TWENTY	$C_1)$
v_5	\rightarrow	$(S_5$	Adams	THIRTY	$C_3)$

50.3 Databases with Additional Semantics

Relational theory assumes everything is a Cantor set. In other words, the interactions among real world objects (entities or attribute values respectively) are "forgotten" in the relational modeling. In practical database processing, additional semantics in attribute domain are often processed. For example, in numerical attributes, the order of numbers is often used in SQL statements by human operators. Therefore these additional semantics implicitly *exist* in the stored database. To capture such additional semantics in data mining, we need a data model which is semantically richer than relational.

What would be the "correct" mathematical structure of real world objects? We will follow the first order logic; the universe and attribute domains are assumed to have relational structures. As a first step, we will confine ourselves to the simplest kind of relational structure, namely, *binary* relations.

In Table 50.2, we give an example of a binary relation defining "near"-semantics on CITY. Note that a binary relation B define a binary neighborhood $B_p = \{x \mid x B p\}$ at every p -called a binary granular structure. A relation with such additional semantics defines a binary granular structure on the universe V , that is the universe is equipped with a finite family of named binary relations.

Table 50.2. "Near"-Binary Relation

<i>CITY</i>	<i>CITY</i>
<i>C</i> ₁	<i>C</i> ₁
<i>C</i> ₁	<i>C</i> ₂
<i>C</i> ₂	<i>C</i> ₂
<i>C</i> ₂	<i>C</i> ₁
<i>C</i> ₂	<i>C</i> ₃
<i>C</i> ₃	<i>C</i> ₃
<i>C</i> ₃	<i>C</i> ₂

Table 50.3. Binary Granular Structure; Relation with additional semantics

the center	Elementary Granule encoded label	Attribute value meaningful name
*	<i>S#</i> (*)	*
*	<i>SNAME</i> (*)	*
<i>v</i> ₁ , <i>v</i> ₄	STATUS(10010)	TWENTY
<i>v</i> ₂ , <i>v</i> ₃	STATUS(01100)	TEN
<i>v</i> ₅	STATUS(00001)	THIRTY
<i>v</i> ₁ , <i>v</i> ₄	<i>CITY</i> (11110)	<i>C</i> ₁
<i>v</i> ₂ , <i>v</i> ₃	<i>CITY</i> (11111)	<i>C</i> ₂
<i>v</i> ₅	<i>CITY</i> (01101)	<i>C</i> ₃

50.4 Mining Real World or Its Representations

What is data mining? The common answer is essentially "to find the pattern in data." This is not entirely accurate; we would like to amend the notion as follows: The goal of data mining is to find patterns in Real World, represented by the given data. For convenience, we will denote the real world by RW and the data (knowledge representation) by KR.

For example, we will not be interested in a discovered rule, say,

"all data are represented by 5 characters."

Because this is a pattern of KR, not RW. To show that a discovered pattern in a KR is, indeed, a pattern of RW. We need to show that the pattern is INVARIANT under attribute transformations. In other words, the pattern *also exists* in other knowledge representations. However, we can take the following alternate approach:

Find the patterns in the mathematical structure, RW, of Real World.

For relational data base, the mathematical structure of RW is the rough granular structure (or knowledge base, if we use Pawlak's terminology); see Table 50.3. If we conduct the data mining in such a structure, it is RW mining; no attribute transformations are needed. In this paper, we extend this approach to "real world" databases.

50.5 Clustered Association Rules-Mining Semantically

Machine oriented model uses granules as its attribute values, so any logical formula is translated to set theoretical formula of granules. However, we should note that attribute values are semantically related, so in processing any logical formula based on attribute values, it is important that one checks the continuity (namely, see if it respects the semantics). We will call any pattern or rule that respects the semantics a *clustered pattern* or *clustered rule*. Let c and d be two attribute values in a relation

Definition Clustered Association rules

1. A pair (c, d) in a given relation is one-way ($c \longrightarrow d$) continuous (or clustered) if every point x in the elementary neighborhood B_c there is at least one y in B_d such that (x, y) is in the given relation.
2. A pair (c, d) in a given relation is a two way continuous (or clustered) if $(c \longrightarrow d)$ and $(d \longrightarrow c)$ are both continuous.
3. Clustered association rule: A pair (c, d) is an association rule iff the pair is an association rule and two way continuous.
4. Soft association rule: A pair (c, d) is a soft association rule, if $\text{Card}(NEIGH(c) \cap NEIGH(d)) \geq \text{threshold}$. [50.1], [50.2]

Here is some of our experimental results: see Table 50.4.

Data characteristics and meaning of comments: (1) Rows 100000; (2) Columns 16; (3) Support 500 items; (4) Main Memory size 10 mega bytes; (5) "Generated 56345 2-combinations" means "56345 candidates of length 2 are generated"; (6) "4973 2-large granule" means "4973 candidates meet the support threshold"; (7) "Continuous 4973 2-association rules" means "4973 continuous association rules of length 2 are checked." From the table, it is clear the cost of checking continuity is small.

50.6 Conclusion

The advantage of data mining by granular computing are:

1. it is fast in mining classical relations, granular computing is faster than Apriori [50.5],[50.6] because the "database scan" are replaced by bit operations.
2. the use of granular computing is extended to "real world" databases (semantically richer relations); its cost is small. Moreover, such extra semantics can be used to analyze unexpected rules [50.7].

Table 50.4. Granular and neighborhood method:

Length	Cand	Supp	Rules	Delta	Comment
0	0			0.000s	Start
1	351			2.333s	Generated 351 1-combinations
		351	351	0.000s	Continuous 1-association rules
2	56345			0.130s	Generated 56345 2-combinations
		4973		20.009s	4973 2-large granule
			4973	2.023s	Continuous 4973 2-association rules
3	38109			425.902s	Generated 38109 3-combinations
		3841		13.650s	3841 3-large granule
			3841	0.090s	Continuous 3841 3-association rules
4	3851			205.065s	Generated 3851 4-combinations
		641		1.552s	641 4-large granule
			641	0.010s	Continuous 641 4-association rules
5	100			1.272s	Generated 100 5-combinations.
		11		0.030s	11 5-large granule
			11	0.000s	Continuous 11 5-association rules
6	0			0.000s	Generated 0 6-combinations.
		0	0	0.000s	Continuous 0 6-association rules
				0.000s	Discover Complete
	98756	9817	9817	672.066s	Totals

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51. A Note on Filtration and Granular Reasoning

Tetsuya Murai¹, Michinori Nakata², and Yoshiharu Sato¹

¹ Division of Systems and Information Engineering, Graduate School of Engineering, Hokkaido University, Kita-ku, Sapporo 060-8628, JAPAN
{[murahiko](mailto:murahiko@main.eng.hokudai.ac.jp), [ysato](mailto:ysato@main.eng.hokudai.ac.jp)}@main.eng.hokudai.ac.jp

² Department of Environment and Information Management for Social Welfare, Josai International University, Togane, Chiba 283-855, JAPAN
nakata@jiu.ac.jp

The filtration method in modal logic is considered to develop a way of formulating an aspect of granular reasoning, which, roughly speaking, means human reasoning based on granularity. The method, however, originates in purely logical problems like decidability. Then, for our purpose, an extended concept of relative filtration is newly introduced using lower and upper approximations in rough set theory. An example of reasoning process using the relative filtration is illustrated.

51.1 Introduction

This paper aims to provide a small step for formulating an aspect of *granular reasoning*. What, however, is granular reasoning? Although, as far as the authors know, there seems to have been no consensus of what it means as a technical term, it would indicate some mechanism for reasoning using rough set theory (Pawlak[51.3]) and granular computing (Lin[51.2]).

Our point of departure is the *filtration* method in modal logic(Chellas [51.1]). It is a standard way of proving finite determination and decidability. The basic idea of filtration method is to generate a kind of quotient model from the original one so that its set of possible worlds is finite. Usually, the method is performed using a given finite set of sentences to which we pay attention with respect to purely logical problems.

When, however, we deal with problems beyond pure logic, we often find ourselves paying attention to proper subsets of such given set of sentences. For the purpose, we introduce a concept of *relative filtration*, an extended definition of filtration with approximation in rough set theory. Finally we illustrate a formulation of human reasoning where a model is not kept fixed but is changed into a new one using the relative filtration whenever required.

51.2 Preliminaries

A modal language $\mathcal{L}_{ML}(\mathcal{P})$ is formed from a given countable set of atomic sentences \mathcal{P} in the usual way with a standard set of logical connectives inclu-

ding the two modal operators. For a sentence p in $\mathcal{L}_{ML}(\mathcal{P})$, its *subsentences* are defined in the usual recursive way. Let $Sub(p)$ be the set of subsentences of p . A set Γ of sentences is said to be *closed under subsentences* just in case $Sub(p) \subseteq \Gamma$ for every p in Γ . Let $\mathcal{P}_p \stackrel{\text{def}}{=} \mathcal{P} \cap Sub(p)$. Also, for the set Γ of sentences, let $\mathcal{P}_\Gamma \stackrel{\text{def}}{=} \cup_{p \in \Gamma} \mathcal{P}_p$.

A *Kripke model* \mathcal{M} is a structure $\langle W, R, V \rangle$, where W is a non-empty set of *possible worlds* and R is an *accessibility relation* on W , and V is a *valuation*, which assigns a subset in W to each atomic sentence \mathbf{p} in \mathcal{P} . Define $\mathcal{M}, w \models \mathbf{p}$ iff $w \in V(\mathbf{p})$. It means that a sentence p is true at a possible world w in \mathcal{M} . \models is extended for every compound sentence in the usual way. The set of possible worlds $\|p\|^\mathcal{M} \stackrel{\text{def}}{=} \{w \in W \mid \mathcal{M}, w \models p\}$ is called the *proposition* of p in \mathcal{M} .

Given a Kripke model $\mathcal{M} = \langle W, R, V \rangle$, let Γ be a set of sentences closed under subsentences. Two worlds w, w' in W is said to be Γ -*equivalent*, written $w \sim_\Gamma w'$, when, for every sentence p in Γ , $\mathcal{M}, w \models p$ iff $\mathcal{M}, w' \models p$. Then, a *filtration of \mathcal{M} through Γ* (or, Γ -*filtration* of \mathcal{M} , for short) is defined as a structure $\mathcal{M}_\Gamma = \langle W_\Gamma, R_\Gamma, V_\Gamma \rangle$, where $W_\Gamma \stackrel{\text{def}}{=} W / \sim_\Gamma$, R_Γ is a relation on W_Γ satisfying several conditions (for details, see Chellas[51.1], p.101), and, for each atomic sentence \mathbf{p} in \mathcal{P}_Γ , $V_\Gamma(\mathbf{p}) \stackrel{\text{def}}{=} \{[w]_{\sim_\Gamma} \mid w \in V(\mathbf{p})\}$. With respect to the filtration, the following remarkable result is obtained: for every p in Γ , $\mathcal{M} \models p$ iff $\mathcal{M}_\Gamma \models p$. Note that, if $|\Gamma| = n$, then $|W / \sim_\Gamma| \leq 2^n$.

51.3 Relative Filtration with Approximation

Given a Kripke model $\mathcal{M} = \langle W, R, V \rangle$, let Γ be a set of sentences closed under subsentences and Δ be a non-empty subset of Γ , which is also assumed to be closed under subsentences. In this paper, we call elements in Γ and $\Gamma^C (= \mathcal{L}_{ML}(\mathcal{P}) \setminus \Gamma)$, respectively, *explicit* and *implicit* sentences. Also, we call elements in Δ and $\Gamma \setminus \Delta$, respectively, *focal* and *marginal* sentences.

The filtration that we want to formulate in what follows contains the set of possible worlds W_Δ and accessibility relation R_Δ . The difference is its valuation (let be V' , tentatively). Truth values for every focal atomic sentence in \mathcal{P}_Δ can be defined in the same way in the usual Δ -filtration of \mathcal{M} . In general, however, we cannot determine truth values for marginal atomic sentences in $\mathcal{P}_\Gamma \setminus \mathcal{P}_\Delta$.

For example, consider the Kripke model \mathcal{M} with $W = \{w_1, w_2, \dots, w_6\}$ and valuation V given in Fig. 51.3. Let $\Gamma = \{\mathbf{p}_1, \mathbf{p}_2, \mathbf{p}_3\} (= \mathcal{P}_\Gamma)$ and $\Delta = \{\mathbf{p}_1, \mathbf{p}_2\} (= \mathcal{P}_\Delta)$. Then, by equivalence relation \sim_Δ , the following quotient set of four new possible worlds (equivalence classes) is generated: $W_\Delta = \{[w_1]_{\sim_\Delta}, [w_2]_{\sim_\Delta}, [w_4]_{\sim_\Delta}, [w_6]_{\sim_\Delta}\}$. The truth values for \mathbf{p}_1 and \mathbf{p}_2 in \mathcal{P}_Δ can be assigned in the same way in the usual Δ -filtration because every element in each equivalence class (newly generated possible world) has the same truth value of the original valuation. Note that

$$\|\mathbf{p}_1\|^{\mathcal{M}} = [w_1]_{\sim_{\Delta}} + [w_2]_{\sim_{\Delta}}, \quad \|\mathbf{p}_2\|^{\mathcal{M}} = [w_1]_{\sim_{\Delta}} + [w_4]_{\sim_{\Delta}},$$

where + denotes the direct sum. Thus, in terms of rough set theory[51.3], for every sentence p in Δ , $\|p\|^{\mathcal{M}}$ is a \sim_{Δ} -definable set. For a marginal sentence \mathbf{p}_3 , since, for all w in $[w_1]_{\sim_{\Delta}}$, $w \in V(\mathbf{p}_3)$ and, for all w in $[w_6]_{\sim_{\Delta}}$, $w \notin V(\mathbf{p}_3)$, so, we can assign, respectively, 1 and 0 to \mathbf{p}_3 at two newly generated worlds $[w_1]_{\sim_{\Delta}}$ and $[w_6]_{\sim_{\Delta}}$. For a new world $[w_2]_{\sim_{\Delta}}$, on the other hand, the two original worlds w_2, w_3 in $[w_2]_{\sim_{\Delta}}$ have different states: $w_2 \in V(\mathbf{p}_3)$ and $w_3 \notin V(\mathbf{p}_3)$. Thus we no longer uniquely determine $V'(\mathbf{p}_3)$ with respect to $[w_2]_{\sim_{\Delta}}$. We have the same result for $[w_4]_{\sim_{\Delta}} = \{w_4, w_5\}$. Hence, in general, we can give only a *partial* definition of V' .

V	\mathbf{p}_1	\mathbf{p}_2	\mathbf{p}_3	\dots
w_1	1	1	1	\dots
w_2	1	0	1	\dots
w_3	1	0	0	\dots
w_4	0	1	1	\dots
w_5	0	1	0	\dots
w_6	0	0	0	\dots

→

V'	\mathbf{p}_1	\mathbf{p}_2	\mathbf{p}_3
$[w_1]_{\sim_{\Delta}}$	1	1	1
$[w_2]_{\sim_{\Delta}}$	1	0	(which of 1,0 ?)
$[w_4]_{\sim_{\Delta}}$	0	1	(which of 1,0 ?)
$[w_6]_{\sim_{\Delta}}$	0	0	0

Fig. 51.1. Partiality of valuation when making relative filtration.

Here note that

$$[w_1]_{\sim_{\Delta}} \subseteq \|\mathbf{p}_3\|^{\mathcal{M}} \subseteq [w_1]_{\sim_{\Delta}} + [w_2]_{\sim_{\Delta}} + [w_4]_{\sim_{\Delta}}.$$

by which we have

$$\underline{\sim_{\Delta}}(\|\mathbf{p}_3\|^{\mathcal{M}}) = [w_1]_{\sim_{\Delta}}, \quad \overline{\sim_{\Delta}}(\|\mathbf{p}_3\|^{\mathcal{M}}) = [w_1]_{\sim_{\Delta}} + [w_2]_{\sim_{\Delta}} + [w_4]_{\sim_{\Delta}}$$

in terms of rough set theory. Thus, we can introduce the concept of approximation in rough set theory into relative filtration. This means that we have two kinds of definition of valuation in the following way.

Definition 51.3.1. For every explicit atomic sentence \mathbf{p} in Γ , *lower* and *upper valuation through Δ relative to Γ* (or, *lower* and *upper Δ/Γ -valuation*, for short) are defined by, respectively,

1. $\underline{V}_{\Delta/\Gamma}(\mathbf{p}) \stackrel{\text{def}}{=} \{[w]_{\sim_{\Delta}} \mid [w]_{\sim_{\Delta}} \subseteq \|\mathbf{p}\|^{\mathcal{M}}\} = \{[w]_{\sim_{\Delta}} \mid [w]_{\sim_{\Delta}} \subseteq \underline{\sim_{\Delta}}(\|\mathbf{p}\|^{\mathcal{M}})\}$
2. $\overline{V}_{\Delta/\Gamma}(\mathbf{p}) \stackrel{\text{def}}{=} \{[w]_{\sim_{\Delta}} \mid [w]_{\sim_{\Delta}} \cap \|\mathbf{p}\|^{\mathcal{M}} \neq \emptyset\} = \{[w]_{\sim_{\Delta}} \mid [w]_{\sim_{\Delta}} \subseteq \overline{\sim_{\Delta}}(\|\mathbf{p}\|^{\mathcal{M}})\}$.

Thereby, we have the following two kinds of filtration:

Definition 51.3.2.

1. A *lower filtration of \mathcal{M} through Δ relative to Γ* (or, *lower Δ/Γ -filtration of \mathcal{M}* , for short) is defined by

$$\underline{\mathcal{M}}_{\Delta/\Gamma} \stackrel{\text{def}}{=} \langle W_{\Delta}, R_{\Delta}, \underline{V}_{\Delta/\Gamma} \rangle,$$

2. An upper filtration of \mathcal{M} through Δ relative to Γ (or, upper Δ/Γ -filtration of \mathcal{M}) is defined by

$$\overline{\mathcal{M}_{\Delta/\Gamma}} \stackrel{\text{def}}{=} \langle W_{\Delta}, R_{\Delta}, \overline{V_{\Delta/\Gamma}} \rangle .$$

Lemma 51.3.1. In lower and upper Δ/Γ -filtrations of \mathcal{M} , for a marginal sentence p in set difference $\Gamma \setminus \Delta$, we have, respectively

1. $\overline{\mathcal{M}_{\Delta/\Gamma}}, [w]_{\sim_{\Delta}} \models p \Rightarrow \mathcal{M}, w \models p$,
2. $\mathcal{M}, w \models p \Rightarrow \overline{\mathcal{M}_{\Delta/\Gamma}}, [w]_{\sim_{\Delta}} \models p$.

51.4 Example of Granular Reasoning

Let us consider the following reasoning process:

(p1)	Socrates is Human.
(p2)	Human is Mortal.
(c)	Socrates is Mortal.

First, we formulate a model. Given $\mathcal{P} = \{\text{Human, Mortal, } \dots\dots\}$, consider a model $\mathcal{M} = \langle W, R, V \rangle$, where $W = \{\text{Socrates, Plato, Tweety, Zeus, } \dots\}$, R is an arbitrary relation on W , and V is defined by

V	Human	Mortal	$\dots\dots$
Socrates	1	1	$\dots\dots$
Plato	1	1	$\dots\dots$
Tweety	0	1	$\dots\dots$
Zeus	0	0	$\dots\dots$
$\dots\dots$	$\dots\dots$	$\dots\dots$	$\dots\dots$

Let $\Gamma = \{\text{Human, Mortal}\}$ and $\Delta = \{\text{Human}\}$. At the first step, Premise (p1) can be translated into

$$\mathcal{M}, \text{Socrates} \models \text{Human} \tag{51.1}$$

in the usual way in rough set theory. At the second step, in order to translate Premise (p2), we need a lower Human/Γ -filtration. That is, if we define $w \sim_{\text{Human}} w'$ by $\mathcal{M}, w \models \text{Human}$ iff $\mathcal{M}, w' \models \text{Human}$, then we have

$$W/\sim_{\text{Human}} = \{\|\text{Human}\|^{\mathcal{M}}, (\|\text{Human}^{\mathcal{M}}\|^{\mathcal{C}})\}.$$

Then, we can translate Premise (p2) into

$$\overline{\mathcal{M}_{\text{Human}/\Gamma}}, \|\text{Human}\|^{\mathcal{M}} \models \text{Mortal}. \tag{51.2}$$

At the third step, by Formula (51.1), we have

$$\|\text{Human}\|^{\mathcal{M}} = [\text{Socrates}]_{\sim_{\text{Human}}}$$

so, by Formula (51.2), we have

$$\underline{\mathcal{M}_{\text{Human}/\Gamma}, [\text{Socrates}]_{\sim\text{Human}}} \models \text{Mortal}. \quad (51.3)$$

At the final step, by Lemma 51.3.1 and Formula (51.3), we can conclude

$$\mathcal{M}, \text{Socrates} \models \text{Mortal}, \quad (51.4)$$

which is just the translation of Conclusion (c). Hence, we can represent our example of reasoning by the following four steps:

$$\begin{array}{l} (51.1) \mathcal{M}, \text{Socrates} \models \text{Human}, \\ (51.2) \underline{\mathcal{M}_{\text{Human}/\Gamma}, \|\text{Human}\|^{\mathcal{M}}} \models \text{Mortal}} \\ (51.3) \underline{\underline{\mathcal{M}_{\text{Human}/\Gamma}, [\text{Socrates}]_{\sim\text{Human}}} \models \text{Mortal}}} \\ \hline (51.4) \mathcal{M}, \text{Socrates} \models \text{Mortal}. \end{array}$$

51.5 Concluding Remarks

The main characteristic of human reasoning is resource-boundedness. We cannot have unlimited ability of reasoning. Thus if we keep to fix our model for reasoning, then we must run with a great number of detailed facts. Thus we must ignore anything that is unnecessary to the current step of our reasoning. So what we should explore is a way of disregarding such many irrelevant things and our proposal is to adopt a filtration-like method. In fact, from the first to the second steps in the previous section, we use relative filtration, which plays a part like 'zooming in' in reasoning process. Then we can disregard details of our world that have no connection with the step. From the second to the third steps, on the other hand, a kind of inverse operation of filtration is used as if its effect is 'zooming out.' Then we can restore some of the details in order to have some conclusion about our world. Hence, if reasoning mechanism contains such kind of operations like zooming in and out, then we can focus our attention into what is essentially needed for each step of reasoning process.

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52. A Note on Conditional Logic and Association Rules

Tetsuya Murai¹, Michinori Nakata², and Yoshiharu Sato¹

¹ Division of Systems and Information Engineering, Graduate School of Engineering, Hokkaido University, Kita-ku, Sapporo 060-8628, JAPAN
{`murahiko`, `ysato`}@`main.eng.hokudai.ac.jp`

² Department of Environment and Information Management for Social Welfare, Josai International University, Togane, Chiba 283-855, JAPAN
`nakata@jiu.ac.jp`

Association rules in data mining are considered from a point of view of conditional logic and rough sets. In our previous work, given an association rule in some fixed database, its corresponding Kripke model was formulated. Then, two difficulties in the formulation were pointed out: limitation of the form of association rules and limited formulation of the models themselves. To resolve the defects, Chellas's conditional logic was introduced and thereby, the class of conditionals in conditional logic can be naturally regarded as containing the original association rules. In this paper, further, an extension of conditional logic is introduced for dealing with association rules with intermediate values of confidence based on the idea of fuzzy-measure-based graded modal logic.

52.1 Introduction

The recent rapid progress of computer technology enables us to analyze a massive number of transaction data in commercial database systems. Such direction has provoked various ways of knowledge discovery from large database and, among them, a mining of the so-called *association rules* proposed by Agrawal et al.[52.1] has obtained the widespread recognition that it is one of the most active themes of data mining.

In our previous paper[52.9], we investigated logical meaning of association rules from a point of view of Chellas's conditional logic[52.4] and Pawlak's rough sets[52.10]. Thereby, we obtained a relationship between Chellas's conditional logic and association rules with full confidence. The logic shows the difference between material implication and conditional, so our previous result enables us to deal with exact inference on association rules as conditionals as well as an extension of the form of association rules.

In this paper, as a next step of our previous work, we present an extension of conditional logic based on the idea of fuzzy-measure-based graded modal logic (cf. Murai et al.[52.6, 52.7, 52.8]), in which we can represent association rules with intermediate degrees of confidence.

52.2 Association Rules

Let \mathcal{I} be a finite set of *items*. Any subset in \mathcal{I} is called an *itemset* in \mathcal{I} . An itemset can be a (possible) *transaction*. A *database* \mathcal{D} is defined as a set of actual transactions, so $\mathcal{D} \subseteq 2^{\mathcal{I}}$. For an itemset $X (\subseteq \mathcal{I})$, its *degree of support* $s(X)$ is defined by $s(X) \stackrel{\text{def}}{=} |\{T \in \mathcal{D} \mid X \subseteq T\}|/|\mathcal{D}|$, where $|\cdot|$ is a size of a set. Given a set of items \mathcal{I} and a database \mathcal{D} , an *association rule*[52.1, 52.2] is an implication of the form $X \implies Y$, where X and Y are itemsets in \mathcal{I} with $X \cap Y = \emptyset$. An association rule $r = (X \implies Y)$ holds in \mathcal{D} with *confidence* $c(r)$ ($0 \leq c \leq 1$) iff $c(r) = s(X \cup Y)/s(X)$. An association rule $r = (X \implies Y)$ has a *degree of support* $s(r)$ ($0 \leq s \leq 1$) in \mathcal{D} iff $s(r) = s(X \cup Y)$. Mining of association rules is actually performed by generating all rules that have certain minimum support (denoted *minsup*) and minimum confidence (denoted *minconf*) that a user specifies. Consult, e.g., [52.1, 52.2, 52.3] for details of such algorithms for finding association rules.

52.3 Previous Works

We describe association rules in a Kripke model. Given a set of items \mathcal{I} and a database \mathcal{D} , we construct a modal language $\mathcal{L}_{\text{ML}}(\mathcal{I})$ in the usual way[52.4], where we regard any item as an atomic sentence.

Definition 52.3.1 ([52.9]). For a given association rule $r = (x \implies y)$, its corresponding finite Kripke model \mathcal{M}_r is defined as a structure $\langle W_{\mathcal{D}}, R_X, V \rangle$, where (1) $W_{\mathcal{D}} = \mathcal{D}$, (2) for any T, T' in $W_{\mathcal{D}}$, $TR_X T'$ iff $T \cap X = T' \cap X$, so R_X is an equivalence relation on W , and (3) for any item x in \mathcal{I} , $V_r(x, T) = \text{true}$ iff $x \in T$.

Because R_X is an equivalence relation, the modal operators defined in this model \mathcal{M}_r satisfy axiom schemata of $KT5(= S5)$. Note that the model described here depends on the premise x of a given association rule.

Definition 52.3.2 ([52.9]). For an association rule $r = (X \implies Y)$, let $X = \{x_1, \dots, x_m\}$ and $Y = \{y_1, \dots, y_n\}$. Then, two sentences p_X and p_Y are defined by

$$\begin{aligned} p_X &\stackrel{\text{def}}{=} x_1 \wedge \dots \wedge x_m = \bigwedge_{x_i \in X} x_i, \\ p_Y &\stackrel{\text{def}}{=} y_1 \wedge \dots \wedge y_n = \bigwedge_{y_i \in Y} y_i. \end{aligned}$$

Then, we have the next theorem:

Theorem 52.3.1 ([52.9]). For an association rule $r = (X \implies Y)$ and its corresponding model \mathcal{M}_r ,

$$c(X \implies Y) = 1 \text{ iff } \mathcal{M}_r \models p_X \rightarrow p_Y,$$

where, in general, $\mathcal{M} \models p$ means that p is true at any world in \mathcal{M} .

Now we find the following two problems:

1. Limited form of association rules whose antecedent and consequent both can take only the form of conjunction.
2. Limited formulation of the models that depends on the fixed antecedent of a given association rule.

To resolve these defects, in [52.9], we introduced Chellas's conditional logic[52.4].

Given a set of items \mathcal{I} and a database \mathcal{D} , we construct a language $\mathcal{L}_{\text{CL}}(\mathcal{I})$ for conditional logic[52.4], where the difference of formation rules is

$$\text{if } p, p' \in \mathcal{L}_{\text{CL}}(\mathcal{I}) \text{ then } (p \triangleright p') \in \mathcal{L}_{\text{CL}}(\mathcal{I}),$$

where \triangleright expresses 'conditional.'

Definition 52.3.3 ([52.9]). For a given database \mathcal{D} , its corresponding finite conditional model $\mathcal{M}_{\mathcal{D}}$ is defined as a structure $\langle W_{\mathcal{D}}, f_{\mathcal{D}}, V_{\mathcal{D}} \rangle$, where (1) $W_{\mathcal{D}} \stackrel{\text{def}}{=} \mathcal{D}$, (2) for any world (transaction) T in $W_{\mathcal{D}}$ and any set of itemsets \mathcal{X} , $f_{\mathcal{D}}(T, \mathcal{X}) \stackrel{\text{def}}{=} \mathcal{X}$, and (3) for any item x in \mathcal{I} , $V_{\mathcal{D}}(x, T) = \text{true}$ iff $x \in T$.

Then we have the following theorem:

Theorem 52.3.2 ([52.9]). Given a database \mathcal{D} and its corresponding conditional model $\mathcal{M}_{\mathcal{D}}$, for arbitrary association rule $r = (X \implies Y)$,

$$\begin{aligned} c(r) = 1 & \text{ iff } \mathcal{M}_{\mathcal{D}} \models p_X \triangleright p_Y, \\ 0 < c(r) < 1 & \text{ iff } \mathcal{M}_{\mathcal{D}} \models \neg((p_X \triangleright p_Y) \vee (p_X \triangleright \neg p_Y)), \\ c(r) = 0 & \text{ iff } \mathcal{M}_{\mathcal{D}} \models p_X \triangleright \neg p_Y. \end{aligned}$$

The theorem provides us the rigid correspondence between association rules with full and no confidence and a subclass of conditionals in conditional logic. Thus, in the framework of conditional logic, we can regard the set of conditionals as an extension of association rules.

52.4 Graded Conditional Logic

In this section, we introduce a graded minimal conditional logic in order to make direct treatment of intermediate degrees of confidence of association rules. For minimal conditional models, see Chellas[52.4]. Given a set of items \mathcal{I} , a language $\mathcal{L}_{g\text{CL}}(\mathcal{I})$ for graded conditional logic is formed from \mathcal{I} in the usual way, where the difference is

$$\text{if } p, p' \in \mathcal{L}_{g\text{CL}}(\mathcal{I}) \text{ and } 0 < k \leq 1 \text{ then } (p \triangleright_k p') \in \mathcal{L}_{g\text{CL}}(\mathcal{I}),$$

where \triangleright_k is *graded conditional* for $0 < k \leq 1$.

Let us formulate a finite graded conditional model $\mathcal{M}_{g\mathcal{D}}$ for a given database \mathcal{D} .

Definition 52.4.1. A finite *graded minimal conditional model* $\mathcal{M}_{g\mathcal{D}}$ is a structure $\langle W_{\mathcal{D}}, \{g_k\}_{0 < k \leq 1}, V_{\mathcal{D}} \rangle$, where

$$g_k(w, \mathcal{X}) \stackrel{\text{def}}{=} \{\mathcal{Y} \in 2^{W_{\mathcal{D}}} \mid \frac{|\mathcal{X} \cap \mathcal{Y}|}{|\mathcal{X}|} \geq k\}.$$

The basic idea of this definition is the same as in fuzzy-measure-based models for graded modal logic (cf. [52.6, 52.7, 52.8]). After all, in this kind of models, the truth condition of graded conditional is defined by

$$\begin{aligned} V(p \triangleright_k q, w) = \text{true} & \text{ iff } \|q\|^{\mathcal{M}_{g\mathcal{D}}} \in g_k(w, \|p\|^{\mathcal{M}_{g\mathcal{D}}}) \\ & \text{ iff } \frac{\|\|p\|^{\mathcal{M}_{g\mathcal{D}}} \cap \|q\|^{\mathcal{M}_{g\mathcal{D}}}\|}{\|\|p\|^{\mathcal{M}_{g\mathcal{D}}}\|} \geq k. \end{aligned}$$

Because we use probability for the definition of the function g_k , we have the soundness results based on fuzzy-measure-based semantics (cf. [52.6, 52.8]) shown in the following table.

Table 52.1. Soundness results of graded conditionals.

$0 < k \leq \frac{1}{2}$	$\frac{1}{2} < k < 1$	$k=1$	Rules and Axiom schemata
○	○	○	RCEA. $\frac{p \leftrightarrow p'}{(p \triangleright_k q) \leftrightarrow (p' \triangleright_k q)}$
○	○	○	RCEC. $\frac{q \leftrightarrow q'}{(p \triangleright_k q) \leftrightarrow (p \triangleright_k q')}$
○	○	○	RCM. $\frac{q \rightarrow q'}{(p \triangleright_k q) \rightarrow (p \triangleright_k q')}$
○	○	○	RCR. $\frac{(q \wedge q') \rightarrow r}{((p \triangleright_k q) \wedge (p \triangleright_k q')) \rightarrow (p \triangleright_k r)}$
○	○	○	RCN. $\frac{q}{p \triangleright_k q}$
		○	RCK. $\frac{(q_1 \wedge \dots \wedge q_n) \rightarrow q}{((p \triangleright_k q_1) \wedge \dots \wedge (p \triangleright_k q_n)) \rightarrow (p \triangleright_k q)}$
○	○	○	CM. $(p \triangleright_k (q \wedge r)) \rightarrow (p \triangleright_k q) \wedge (p \triangleright_k r)$
○	○	○	CC. $(p \triangleright_k q) \wedge (p \triangleright_k r) \rightarrow (p \triangleright_k (q \wedge r))$
○	○	○	CR. $(p \triangleright_k (q \rightarrow r)) \leftrightarrow (p \triangleright_k q) \wedge (p \triangleright_k r)$
○	○	○	CN. $p \triangleright_k \top$
○	○	○	CP. $\neg(p \triangleright_k \perp)$
		○	CK. $(p \triangleright_k (q \rightarrow r))(p \triangleright_k q) \rightarrow (p \triangleright_k r)$
	○	○	CD. $\neg((p \triangleright_k q) \wedge (p \triangleright_k \neg q))$
○			CD_C. $(p \triangleright_k q) \vee (p \triangleright_k \neg q)$

The conditional probability adopted in Definition 52.4.1 is nothing but the degree of confidence when it is applied to an association rule $r = (X \implies Y)$. In fact, by easy calculation, we have

$$c(r) = \frac{\|\|p_X\|^{\mathcal{M}_{g\mathcal{D}}} \cap \|p_Y\|^{\mathcal{M}_{g\mathcal{D}}}\|}{\|\|p_X\|^{\mathcal{M}_{g\mathcal{D}}}\|}.$$

so, for any transaction T in $W_{\mathcal{D}}$,

$$V(p_X \triangleright_{c(r)} p_Y, T) = \text{true}.$$

Thus we can conclude that an association rule $r = (X \implies Y)$ can be translated into a graded conditional $(p_X \triangleright_k p_Y)$ where $k = c(r)$.

52.5 Concluding Remarks

This paper, as one of a series of our papers on theoretical consideration between association rules and conditional logic, introduced a first step for graded conditionals that correspond to association rules with intermediate degrees of confidence.

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53. Analysis of Self-Injurious Behavior by the LERS Data Mining System

Rachel L. Freeman¹, Jerzy W. Grzymala-Busse², Laura A. Riffel¹, and Stephen R. Schroeder¹

¹Bureau of Child Research, Institute for Life Span Studies, University of Kansas, Lawrence, KS 66045, USA
rfreeman@ukans.edu riffy@peoplepc.com Schroeder@ukans.edu

²Department of Electrical Engineering and Computer Science, University of Kansas, Lawrence, KS 66045, USA
jerzy@eecs.ukans.edu

53.1 Introduction

A large number of individuals with disabilities engage in problem behaviors which are influenced by environmental and social factors [16]. A smaller, but significant, proportion of problem behaviors appear to be maintained by physiological events [4, 11, 16]. Over time, problem behavior maintained primarily by physiological events may be influenced by environmental factors [3]. For these reasons, a more sophisticated assessment approach that considers the interrelation between physiological and environmental factors is needed [9, 16].

The purpose of this descriptive study was to use data mining system LERS to explore the relation between arousal level, environmental events, and the occurrence of problem behavior. The adult subject who participated in this study was diagnosed with severe mental retardation, had visual impairments, and engaged in serious problem behavior. The data from this study were collected by using an athlete's heart rate monitor to gather heart rate every 15 seconds. A fixed time period was identified through the functional assessment where problem behaviors were likely, activities were highly predictable and did not vary, and the subject engaged in roughly the same type of motor movements. A camcorder was turned on at the same time as the heart rate monitor and the researchers coded the tapes later in real time using a software program to record behavioral and environmental events [12, 15]. Two independent observers recorded 30% of all baseline sessions and 34% of all remaining sessions for this subject in order to establish interobserver agreement.

Originally, sequential analysis procedures were used to assess conditional probabilities of heart rate change and problem behavior given predictor conditions [1, 7]. This previous study confirmed that the Polar Heart rate monitor identified unique patterns of heart rate in relation to problem behavior [6].

The problem behaviors identified in this study included self-injury in the form of self-biting and aggressive behaviors, specifically, striking out or attempting to bite others. Disruptive behaviors in the form of throwing objects, pushing away

from a task, or using two hands to raise his chair forcefully upwards while in a sitting position were also assessed. Finally, the functional assessment included self-stimulatory behavior that involved pressing on the carotid artery ("neck press"). Results of the original study indicated that self-biting, aggression towards others, and disruptive behaviors were maintained by escape from non-preferred tasks. Demand statements and the presence of specific activities were identified as antecedent variables that occasioned problem behavior. Evidence gathered during an initial assessment suggested that the act of pressing on the carotid artery triggered internal sensations that were of a reinforcing quality to the subject and tended to occur in the absence of environmental stimuli. The subject's heart rate increased in the 15-second interval following the occurrence of self-biting and aggressive behaviors [6].

In our study 26 sessions were recorded, in this paper we present rules induced from a transformed data set coming from only one such session.

A modified version of this paper was presented at the Japanese Society for Artificial Intelligence International Workshop on Rough Set Theory and Granular Computing, RSTGC-2001 [5].

53.2 Data Mining

The original, raw data set describing self-injurious behavior were divided into two parts. In the first part the subject's heart rate was recorded every 15 seconds. The second data set consisted values of three variables: a combined variable representing the subject's behavior and external stimulus (different codes were used to avoid ambiguity) and two variables representing the moments of time (in seconds, counting from the beginning of the session). The first of these two variables indicated when a specific event started, while the second variable indicated when the event finished.

The main problem was that the original, raw data were *temporal* (time-dependent). Secondly, the original, raw data sets were not synchronized with each other, i.e., they presented situations at different moments of time. The original, raw data sets were eventually transformed into one data, called in the sequel *transformed data set*, processed later by data mining system LERS.

The first step of data preparation was discretization of the numerical variable Heart Rate. The next step of was adding new variables, Behavior-15, Behavior-30, External_Stimulus-15, and External_Stimulus-30, describing values of the variables Behavior and External_Stimulus 15 seconds earlier and 30 seconds earlier, respectively.

In this study, the data mining system LERS (Learning from Examples based on Rough Sets) [8] was used to analyze the relation between the subject's behavior, external stimuli, and heart rate. Rules were induced by algorithm LEM2 [8], a part of the system LERS.

As the first step of LERS processing of the input data file, LERS checks if the input data file is *consistent* (i.e., if the file does not contain conflicting cases). Our data set was inconsistent, therefore, LERS computed *lower* and *upper approxima-*

tions of all concepts. The ideas of lower and upper approximations are fundamental for rough set theory [13, 14]. Rules induced from the lower approximation of the concept *certainly* describe the concept, so they are called *certain*. On the other hand, rules induced from the upper approximation of the concept describe the concept only *possibly* (or *plausibly*), so they are called *possible* [8].

Rules induced from raw, training data are used for classification of unseen, testing data. The classification system of LERS is a modification of the *bucket brigade algorithm* [2, 10]. The decision to which concept a case belongs is made on the basis of three factors: strength, specificity, and support. They are defined as follows: *Strength* is the total number of cases correctly classified by the rule during training. *Specificity* is the total number of attribute-value pairs on the left-hand side of the rule. The matching rules with a larger number of attribute-value pairs are considered more specific. The third factor, *support*, is defined as the sum of scores of all matching rules from the concept. The concept C for which the support (i.e., the sum of all products of strength and specificity, for all rules matching the case), is the largest is a winner and the case is classified as being a member of C .

53.3 Results

Normal heart rate both in the current interval and in the preceding 30-second interval strongly predicted the absence of problem behavior. The absence of behavior was likely when high heart rate and staff praise occurred in the current interval, with very high heart rate in the preceding 15-second interval. Demands and high heart rate 30 seconds prior to an identified interval predicted the absence of problem behavior as well. There was a higher likelihood of disruptive behavior when the subject's heart rate in the current interval, and previous 15, and 30-second interval was very high and an activity was in occurring 15-seconds before the target interval. Disruptive behavior also was predicted when the activity was occurring in the current interval, and there was a very high heart rate in the current, previous 15-second, and 30-second intervals. A disruptive behavior was likely in the presence of very high heart rates 30 seconds, 15 seconds prior to the targeted interval, very high heart rate in the current interval, and an activity in the previous 30 seconds. An uncertain rule similar to this pattern predicted self-biting. In this case, a self-bite was predicted when heart rate in the current interval was very high and the 15 and 30 seconds before the target interval with an activity occurring 30 seconds prior to the behavior. Self-bites were predicted when there was a high heart rate and staff praise occurring 30 seconds before, with high heart rate 15 seconds prior to the behavior and in the current interval. Neck press was predicted when both demand and praise statements had occurred in the previous 30 second interval while heart rate was very high and heart rate remained high in the current interval.

53.4 Conclusions

Intriguing patterns arose from the data providing information about antecedent events in rich detail. Normal heart rate was highly predictive of the absence of problem behavior. High and very high heart rates were more likely to be included in rule statements predicting self-biting, disruptive, and aggressive behavior. Rule statements suggested that activities were more likely to be present in the current interval which provides support for the hypothesis that the subject's behavior was maintained by escape from nonpreferred tasks. Heart rate data collected every 15 seconds created some difficulties interpreting the data. A number of independent and dependent variables would occur within the same 15-second interval, making it difficult to identify whether an external stimulus was actually an antecedent event.

More sensitive heart rate equipment must be used in order to truly explore the relation between heart rate and problem behavior as well as the utility of the data mining LERS system. In addition, a richer set of codes exploring environmental events that influence behavior would increase the consistency of the data and provide a more comprehensive understanding of the variables influencing problem behavior.

Further research is needed to compare the results of the session analyzed in this article with the remaining 25 sessions for this subject. Another option would be to combine the 26 sessions in order to conduct a comprehensive analysis.

This study represents an important first step in the analysis of heart rate, behavior, and environmental events. Despite the challenges encountered in collecting and analyzing heart rate data in real life environments, new methodological approaches are greatly needed to fully understand the link between physiology and behavior. The data mining LERS holds great potential utility for clinical support of individuals with disabilities who engage in problem behavior.

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54. A Clustering Method for Nominal and Numerical Data Based on Rough Set Theory

Shoji Hirano¹, Shusaku Tsumoto¹, Tomohiro Okuzaki², and Yutaka Hata²

¹ Department of Medical Informatics,
Shimane Medical University, School of Medicine
89-1 Enya-cho, Izumo 693-8501, Japan
hirano@ieee.org

² Department of Computer Engineering, Himeji Institute of Technology
2176 Shosha, Himeji 671-2201, Japan

This paper describes a new clustering method based on rough set theory. This method classifies objects according to the indiscernibility relations defined on the basis of relative similarity. First, an initial equivalence relation, which evaluates local similarity of objects, is assigned to every object. Then modification of the initial equivalence relations is performed by examining global relationships among them. An initial equivalence relation will be modified if it gives excessively fine classification to the objects. Consequently, generation of small category is suppressed and adequately coarse clusters are formed. Experimental results on the artificial data showed that this method produced good clustering results for both of nominal and numerical data.

54.1 Introduction

Advances in communication systems and high performance computers enable us to easily collect valuable information from the Internet and to construct databases that store huge amount of information. Clustering has been receiving considerable attention as one of the most promising approaches for revealing underlying structure in such databases. However, the well-known clustering algorithms such as K-means [54.1] and Fuzzy C-Means (FCM) [54.2] have difficulty in handling nominal data since they require calculation of the cluster centers. Although the agglomerative hierarchical clustering method [54.3] enables handling of nominal data by the use of relative similarity, it still has a problem that the clustering result strongly depends on the order of handling objects.

This paper introduces an order-independent clustering method for nominal and numerical data based on rough sets [54.4]. Objects are classified according to the indiscernibility relations defined on the basis of relative similarity. In the first step, we form initial equivalence relations among objects based on their relative similarity, and classify them into some categories according to the relations. Similarity threshold is independently determined

to each object. In the second step, we modify similar equivalence relations into one type of relation so that it represents more simple knowledge which generates adequate number of categories. The optimal clustering result can be obtained by evaluating the cluster validity, defined using upper and lower approximations of a cluster, throughout all clusters generated with various threshold values for modification. In the experiments we demonstrate that this method produces good clustering results for both nominal and numerical data.

54.2 Clustering Method

The method consists of two steps: (1) Assignment of initial equivalence relations and (2) Modification of initial equivalence relations. Step (2) is repeated using various values of modification threshold Th , and the best clustering result which yields maximum validity is obtained.

54.2.1 Initial Equivalence Relation

In the first step, an initial equivalence relation is assigned to each object. Defined on the basis of relative similarity, an equivalence relation splits the entire set into two equivalence classes: one containing similar objects and another containing dissimilar objects. Namely, each relation performs classification by evaluating local similarity between its corresponding object and other objects.

[Definition 1] Initial Equivalence Relation

Let $U = \{x_1, x_2, \dots, x_n\}$ be the set of objects we are interested in, and assume that each object has p attributes represented by nominal or numerical values. An equivalence relation R_i for object x_i is defined by

$$R_i = \{\{P_i\}, \{U - P_i\}\},$$

where

$$P_i = \{x_j \mid s(x_i, x_j) \geq S_i\}, \quad \forall x_j \in U.$$

The notation $s(x_i, x_j)$ denotes similarity between objects x_i and x_j , and S_i denotes a threshold value of similarity for object x_i . The equivalence relation R_i classifies U into two categories: one containing objects similar to x_i and another containing objects dissimilar to x_i . When $s(x_i, x_j)$ is larger than S_i , object x_j is considered to be indiscernible to x_i . Similarity $s(x_i, x_j)$ is calculated as a weighted sum of the Mahalanobis distance $d_M(x_i, x_j)$ of numerical attributes and the Hamming distance $d_H(x_i, x_j)$ of nominal attributes as:

$$s(x_i, x_j) = \frac{p_c}{p} \left(1 - \frac{d_M(x_i, x_j)}{\max_{x_u, x_v \in U} d_M(x_u, x_v)} \right) + \frac{p_d}{p} \left(1 - \frac{d_H(x_i, x_j)}{\max_{x_u, x_v \in U} d_H(x_u, x_v)} \right),$$

where p_c and p_d denote the numbers of numerical and nominal attributes, respectively.

Similarity threshold S_i is determined based on the gradient of similarity. Let $s(x_i, x_j)$ be the similarity arranged in descendant order on j and let $s'(x_i, x_j)$ be the first order derivative of $s(x_i, x_j)$. Then $s'(x_i, x_j)$ is derived as a convolution of $s(x_i, x_j)$ and first derivative of Gaussian function as follows.

$$s'(x_i, x_j) = \int_{-\infty}^{\infty} s(x_i, x_u) \frac{-(j-u)}{\sigma^3 \sqrt{2\pi}} e^{-(j-u)^2/2\sigma^2} du,$$

where $x_j = 1$ and $x_j = 0$ are used for $j < 0$ and $j > n$ respectively. Using mean and standard deviation of $s'(x_i, x_j)$, denoted respectively by $\mu_{s'}(i)$ and $\sigma_{s'}(i)$, we seek the minimal j^* that first satisfies

$$s'(x_i, x_{j^*}) \geq \mu_{s'}(i) + \sigma_{s'}(i)$$

and obtain j^* where similarity decreases largely compared to the others. Finally, S_i is obtained as $S_i = s(x_i, x_{j^*})$.

[End of Definition]

54.2.2 Modification of Equivalence Relations

Objects should be classified into the same category when most of equivalence relations commonly regard them indiscernible. However, these similar objects may be classified into different categories depending on the combination of initial equivalence relations. In such a case, unpreferable clustering result consists of small, fine categories will be obtained.

In the second step, we perform modification of initial equivalence relations in order to suppress excessive generation of small category. When an initial relation classifies two objects into different categories, but the number of relations that regard them indiscernible is larger than a given threshold Th , this relation is modified to include the two objects into the same category.

[Definition 2] Indiscernibility Degree of Objects

An *indiscernibility degree*, $\gamma(x_i, x_j)$, of two objects x_i and x_j is defined as

$$\gamma(x_i, x_j) = \frac{1}{|U|} \sum_{k=1}^{|U|} \delta_k(x_i, x_j),$$

where

$$\delta_k(x_i, x_j) = \begin{cases} 1, & \text{if } [x_k]_{R_k} \cap ([x_i]_{R_k} \cap [x_j]_{R_k}) \neq \phi \\ 0, & \text{otherwise.} \end{cases}$$

[End of Definition]

On giving indiscernibility degree to every pair of objects, modification of each equivalence relation is performed according to the following procedure.

[Definition 3] Modification of Equivalence Relations

Let $R_i, R_j \in \mathbf{R}$ be initial equivalence relations and let $R'_i, R'_j \in \mathbf{R}'$ be equivalence relations after modification. For an initial equivalence relation R_i , a modified equivalence relation R'_i is defined as

$$R'_i = \{\{P'_i\}, \{U - P'_i\}\}$$

where P'_i denotes a subset of objects represented by

$$P'_i = \{x_j \mid \gamma(x_i, x_j) \geq Th\}, \quad \forall x_j \in U.$$

The value Th denotes the lower threshold value of indiscernibility degree to regard x_i and x_j as the indiscernible objects.

[End of Definition]

54.2.3 Evaluation of Validity

Depending on the choice of threshold Th , object number of modified sets of equivalence relations can be obtained in the preceding steps. We then evaluate validity of their clustering results based on the following criteria.

1. *Modification degree*: It represents how largely \mathbf{R} was modified to be \mathbf{R}' . High validity is assigned when \mathbf{R}' was obtained with small modification.
2. *The number of objects in each category*: High validity is assigned when each of categories generated by \mathbf{R}' contains adequate number of objects.

[Definition 4] Validity of Clustering Result

Let U denote the entire set of objects, \mathbf{R} denote a set of initial equivalence relations, and \mathbf{R}' denote the modified set of \mathbf{R} , respectively. Suppose that \mathbf{R}' classifies U into l categories, $U/IND(\mathbf{R}') = \{\mathbf{C}_1, \mathbf{C}_2, \dots, \mathbf{C}_l\}$. A modification degree for k -th category, $\alpha_{\mathbf{R}}(\mathbf{C}_k)$, is defined by

$$\alpha_{\mathbf{R}}(\mathbf{C}_k) = |\underline{\mathbf{R}}\mathbf{C}_k| / |\overline{\mathbf{R}}\mathbf{C}_k|,$$

where $\underline{\mathbf{R}}\mathbf{C}_k$ and $\overline{\mathbf{R}}\mathbf{C}_k$ denote \mathbf{R} -lower and \mathbf{R} -upper approximations of \mathbf{C}_k given below:

$$\underline{\mathbf{R}}\mathbf{C}_k = \bigcup_{x_i \in \mathbf{C}_k} \{[x_i]_{R_i} \mid [x_i]_{R_i} \subseteq \mathbf{C}_k\},$$

$$\overline{\mathbf{R}}\mathbf{C}_k = \bigcup_{x_i \in \mathbf{C}_k} \{[x_i]_{R_i} \mid [x_i]_{R_i} \cap \mathbf{C}_k \neq \phi\}.$$

The number of objects in the k -th category is represented by $|\mathbf{C}_k|$. Total validity of the clustering result, $V(\mathbf{R}')$ is defined by

$$V(\mathbf{R}') = \frac{1}{l} \sum_{k=1}^l (\alpha_{\mathbf{R}}(\mathbf{C}_k) \times |\mathbf{C}_k|).$$

[End of Definition]

54.3 Experimental Results

The proposed method was applied to a two-dimensional numerical data containing 58 objects generated by Neyman-Scott method [54.5]. Results are summarized as follows. Without performing modification of initial equivalence relations, we obtained 10 clusters including 7 small ones. With modification, equivalence relations which contributed to generation of small clusters were modified so that they include similar objects into the close clusters. Consequently, we obtained 3 expected clusters. It required about three seconds to process the numerical data on a workstation (SGI OCTANE2, R12000, 400MHz). More detailed description and results on the BALLOON database [54.6] are available in the original paper[54.7].

54.4 Conclusions

This paper has proposed a rough sets-based clustering method with modification of equivalence relations. In the experiments we demonstrated that the use of relative similarity and modification of initial equivalence relation led to successful classification on both types of data. It remains as a future work to represent knowledge used for classification by using the modified set of equivalence relations.

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55. A Design of Architecture for Rough Set Processor

Akinori Kanasugi

Saitama University, Saitama 338-8570, Japan
kanasugi@super.ees.saitama-u.ac.jp

This paper proposes architecture of rough set processor. The theory of rough sets has a lot of applications such as data mining, decision support system, machine learning and so on. However, no specific processor has been developed. In this paper, the architecture of rough set processor is shown.

55.1 Introduction

Rough set processor is a foundation for large-scale application of the theory. Therefore, this paper proposes architecture of rough set processor, which can solve large-scale problem in real time. In this paper, the architecture of rough set processor is described.

55.2 Architecture

The inputs of rough set processor are decision tables and the outputs are rules, which are represented by logic functions.

The block diagram for the rough set processor is shown in figure 55.1. The processor will run as a co-processor of host computer, sharing “Main Memory”. In this section, data format, execution process, and architecture are described.

55.2.1 Data Format

The input data is one column of discernibility matrix, which has 2,000 binary attributes and one million data. It corresponds to a product of sums expression of logic function. The input data consists of the following fields;

Data: Existence of variables in each logic term;

Sum: Total number of variables in each logic term;

Flag: Flag for covering by cores.

The required memory size is 256 MB for one million logic terms, because one logic term requires 256 bytes.

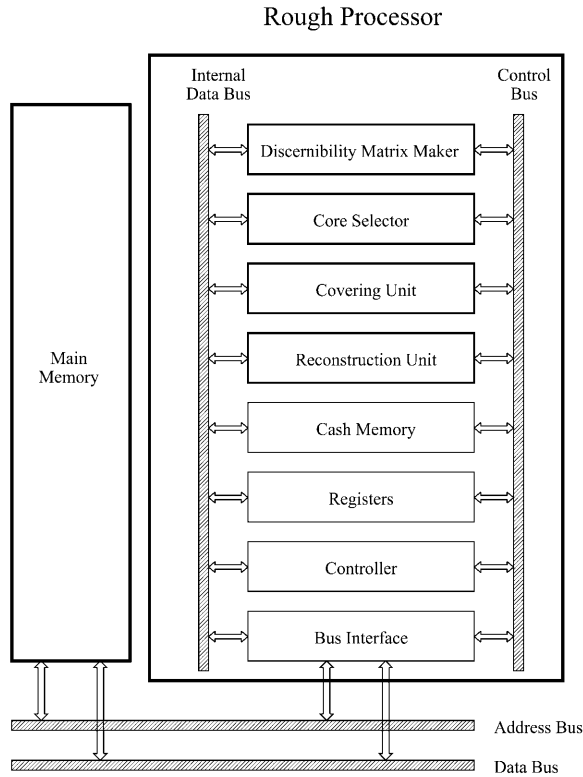


Fig. 55.1. Block diagram of rough set processor.

55.2.2 Execution Process

The execution process consists of two parts, which are pre-process and main process[55.3]. In the pre-process, some sparse terms (rows) are selected as “cores”, and then implying relation reduces input logic functions. In the main process, input logic function is converted to simple sum of products format approximately.

55.2.3 Discernibility Matrix Maker

The task of this unit is conversion from decision table to binary discernibility matrix. This process is very complex, because decision tables include not only binary attributes, but also real number or string attributes. For example, selection of optimized threshold values for real number attributes is an enough complex problem. Therefore, this unit is not treated in the present.

55.2.4 Core Selector

This unit selects the data, which has small value of “Sum” filed, then transfer the row number of selected data to “Core Number Register” in this unit.

55.2.5 Covering Unit

This unit reduces the given function by implying operation with core data. The results of reduction are stored in “Flag” bit. The flag is set “1”, if the row can be deleted, while “0”, if it can’t be deleted.

This implying operation is performed 256 bit in parallel by using four implying units, which consists of 64 implying cells. The implying relation $c \subset a$ is equivalent to $\bar{c} + a$. Therefore, by inverting each bit of core data, conventional OR-gate is available as implying gate.

55.2.6 Reconstruction Unit

The main operations of this unit are,

OP1 Search for dominant logic variables from input function (discernibility matrix).

OP2 Reconstruction of the function by using the above variables.

The main task is **OP1**. For this purpose, it is necessary for counting, while the accuracy is not required. Figure 55.2 shows the block diagram of counter unit. We use the approximated method to reduce operation time and circuit area. The strategies are,

1. **Skip of rows:** The unit counts 20% of data randomly. As the result, the operation speed becomes five times faster without large error, if the input data is large scale and uniform.
2. **Usage of small counter:** We use 8-bits counter while 20 bits counters are required ($10^6 \simeq 2^{20}$). However, all counters have to be shifted right, when one of the counters is overflowed. This approximation makes possible to reduce the size of counters. Therefore, if we use the same chip area, we can increase the degree of parallel. As the results, improvement of operation speed can be performed.

This unit has 64 counters with 8-bit length. The counting operation will be executed in 64 bits parallel. The number of overflow is stored in “Over Flow Counter”. The counting results are shifted left when the data are stored to “Count Cash”. The count cash requires 20 bits \times 2,032 words. The address of data to be counted is decided by “Random-Row-GEN”. “COUNT MASK” is used to reset columns, which are already recognized as dominant attributes.

After the counting, we must find the dominant variable. An accurate method is not necessary for our purpose. Therefore, a simple approximation technique is used[55.3].

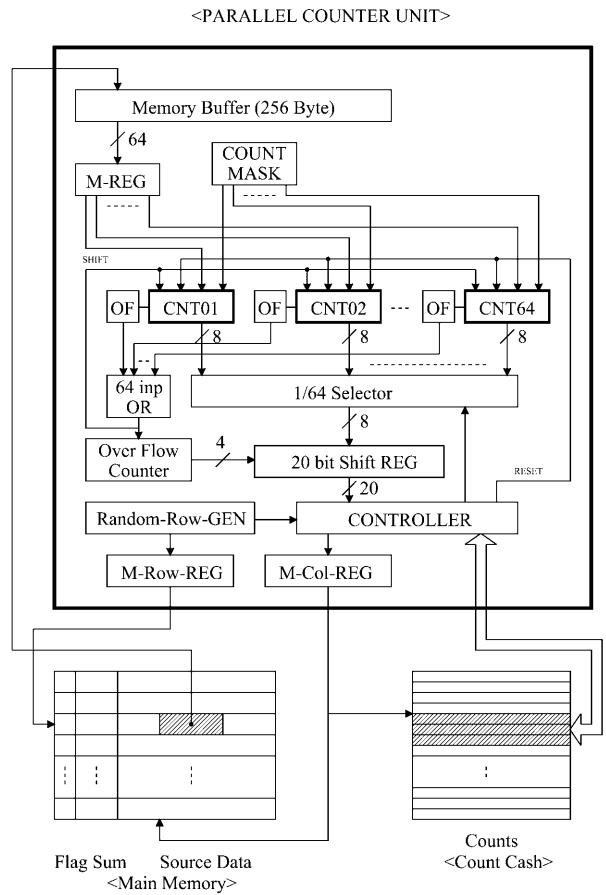


Fig. 55.2. Block diagram of counter unit.

55.2.7 Implementation

To obtain high performance, high-speed data transfer is very important, while the gate switching speed is not so important. Therefore, large-scale and high-speed cash memory should be prepared. The implementation will be done using FPGA (Field Programmable Gate Array) with logic synthesis CAD tools.

55.2.8 Performance Analysis

It is necessary to compare the performance of the rough set processor with software-based tools. We assume that tools run on a RISC machine with large

cash memory and optimized compiler system, because the rough set processor deals with large but simple data processing. The difference in processing of unit data between the processor and software-based tool will be not large. The improvement of performance is mainly achieved by parallel processing. By introducing next parameters,

N_{pc} : degree of parallel in columns,

N_{pr} : degree of parallel in rows,

N_{ft} : number of logic terms in output function,

R_h : ratio of operating speed of the processor and general (RISC) CPU,
the performance improvement is given by

$$R = N_{pc} \cdot N_{pr} \cdot N_{ft} \cdot R_h. \quad (55.1)$$

For example, assuming $N_{pc}=128$, $N_{pr}=4$, $N_{ft}=16$, $R_h=2$, we can obtain $R=16,384$. The key to good performance is design of memory interface system. That is, fast data supply and memory access reduction are important.

55.3 Conclusion

In this paper, the architecture of rough set processor is described. The future works are the logic synthesis, simulation and implement.

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56. The Scope of Chance Discovery

Yukio Ohsawa

Graduate School of Business Science, University of Tsukuba

A "chance" here means an event or a situation with significant impact on human decision making – a new event/situation that can be conceived either as an opportunity or as a risk. The "discovery" of a chance is to become aware of and to explain the significance of a chance, especially if the chance is rare and its significance is unnoticed. Desirable effects of opportunities should be actively promoted, whereas preventive measures should be taken in the case of discovered risks. In other words, chance discovery aims to provide means for inventing or surviving in the future, rather than predicting the future.

The essential aspect of a chance (risk or opportunity) is that it can be the seed of new and significant changes in the near future. The discovery of new opportunities might be more beneficial than reliance on past frequent success-patterns (usually used in prediction methods), because they are not known yet by oneself or one's business rivals. The discovery of new risks might be indispensable to avoid or lessen damage, because they cannot be explained by past frequent damage-patterns. Therefore, being aware of a novel important event without ignoring it as noise in the data is essential for a future success. Besides data mining methods for finding rare but important events from time-series, it is also important to draw humans attention to such events, i.e., to make humans ready to catch chances. In this sense, human-information interactions are highly relevant to chance discovery. Furthermore, chance discovery can be seen as an extension of risk management to computer-aided problem solving where novel situations are involved.

The workshop on Chance Discovery was intended to bring together studies from artificial intelligence, human-computer interaction, social and cognitive sciences, marketing researches, risk management, knowledge discovery and data mining, and other related domains, for presenting breakthroughs to real-world chance discoveries.

Topics from information visualization and other human-information interaction designs, for aiding human awareness and discovery of chances, were discussed earnestly in the workshop, and this part show the best 12 papers.

57. Chance Discovery Using Dialectical Argumentation

Peter McBurney and Simon Parsons

Department of Computer Science
University of Liverpool
Liverpool L69 7ZF United Kingdom
{p.j.mcburney,s.d.parsons}@csc.liv.ac.uk

We propose the use of a dialectical argumentation formalism for chance discovery in domains where knowledge is distributed across a number of distinct knowledge-bases, as in a system of autonomous software agents. Each agent may have only a partial view of a problem, and may have insufficient knowledge to prove particular hypotheses; our formalism provides a means to aggregate across these partial views in a consistent manner. We identify a novel type of dialogue, which we call a discovery dialogue, and propose a formal model for its conduct. We then present locutions and rules for the implementation of these dialogues as dialogue-games.

57.1 Introduction

In 1994-5, the British Government privatized the state-owned national railway monopoly, British Rail. They did this by creating one private company, Railtrack Ltd, to own and operate the physical network of railway track, and then created 25 separate licences, each awarded by competitive tender, to operate train services along these tracks in specific geographic regions. In addition, other companies were created to provide specific services to Railtrack and to the train operating companies, for instance, railway communications. The new private companies also outsourced functions which had previously been undertaken within British Rail, such as carriage ownership and track inspection and maintenance. By one estimate there are now more than 100 companies where previously there was just one. Thus, what was once a single and unified system, is now fragmented, with disparate responsibilities, distributed knowledge and possibly conflicting interests. No one company in the network now has all the information needed to manage it. The results of this were seen on 17 October 2000, when faulty track caused a derailment at Hatfield, killing four people and injuring 70. Although an inquiry still has to establish ultimate responsibility for the accident, knowledge of the faulty track appears to have been known to the company tasked with network inspection, a sub-contractor to Railtrack [57.4].

The problem of interest here is how to identify risks and opportunities (*“Chance Discovery”*) in situations where knowledge is distributed across multiple autonomous agents. We believe that systems of dialectical argumen-

tation, which enable the coherent combination of disparate knowledge types and sources, are applicable to this problem and we present here a formalism for such a system. For simplicity, we assume that the agents involved do not perceive they have divergent economic or other interests, and so are willing to share information fully with each other. We present our formalism in Section 3, after briefly reviewing argumentation and formal dialogue games in Section 2. In earlier work, we presented a similar dialectical argumentation structure for dialogues over risk in environmental domains, which we which termed a *Risk Agora* [57.7]. Accordingly, we call the formalism presented in this paper a *Discovery Agora*. Section 4 concludes the paper.

57.2 Argumentation

In common English usage, an “*argument*” has two meanings: a case for (or against) a particular claim, and a debate between two or more people. Arguments in both senses have been studied by philosophers since at least the time of Aristotle, in a branch of philosophy now called argumentation theory. In this paper, we will use the word *argument* for only the first meaning, and the words *debate* or *dialogue* for the second. Considering arguments as cases for claims, argumentation theory has examined issues such as what constitutes a good or bad argument, under what circumstances is it rational to use non-deductive arguments, and what relationships may exist between distinct arguments. For dialogues and debates, philosophers have explored issues such as how may such debates be organized and structured, what rules are appropriate for different types of interaction, and what impacts arise from variations in these rules. In both areas, philosophers of argumentation have been particularly active since the mid-1950s, perhaps in response to the development of formal, deductive logic in the century before that. See [57.11] for a comprehensive review of argumentation theory, and [57.2] for a review of some applications of argumentation in Artificial Intelligence. In this paper we will use formal dialogue games to model dialogues, so we first discuss different types of dialogues.

In an influential typology, Doug Walton and Erik Krabbe [57.12] identified six primary types of dialogue, distinguished by their initial situations, the goals of each of their participants, and the goals of the dialogue itself (which may differ from those of its participants). The six dialogue types were: *Information-seeking dialogues*, in which participant seeks the answer to some question from another participant; *Inquiries*, in which all participants collaborate to answer some question to which none has the answer; *Persuasion dialogues*, in which one participant seeks to convince others of the truth of some proposition; *Negotiations*, in which participants attempt to divide up a scarce resource; *Deliberations*, in which participants collaborate to decide what actions to take in some situation; and *Eristic* (strife-ridden) dialogues, in which participants quarrel verbally as a substitute to physical

fighting. Most human dialogues may be seen as examples of these six or combinations thereof, although Walton and Krabbe do not claim their typology is comprehensive.

How may specific types of dialogues be modeled? To do this, we draw on the formal dialogue games proposed by philosophers to better understand fallacious modes of reasoning [57.3]. These are games between two or more players, where the “moves” made by the players are locutions, i.e. spoken utterances. Recently, such games have been applied in Artificial Intelligence [57.1], particularly for automated dialogues between autonomous agents, and we have been led to propose a formal model for dialogue-games [57.8]. In our model, it is assumed that the topics of discussion between the participants are represented in some logical language, whose well-formed formulae are denoted by the lower-case Roman letters, p , q , r , etc. The rules of the dialogue-game can be divided into several distinct types:

Commencement Rules: Rules which define the circumstances under which the dialogue commences.

Locutions: Rules which indicate what utterances are permitted. Typically, legal locutions permit participants to assert propositions, permit others to question or contest prior assertions, and permit those asserting propositions which are subsequently questioned or contested to justify their assertions.

Combination Rules: Rules which define the dialogical contexts under which particular locutions are permitted or not, or obligatory or not. For instance, it may not be permitted for a participant to assert a proposition p and subsequently the proposition $\neg p$ in the same dialogue, without in the interim having retracted the former assertion.

Commitments: Rules which define the circumstances under which participants express dialogic commitment to a proposition. Typically, assertion of a claim p in the debate is defined as indicating to the other participants some level of commitment to, or support for, the claim. Since Hamblin [57.3], it is common to track commitments in publicly-accessible stores called Commitment Stores.

Termination Rules: Rules which define the circumstances under which the dialogue ends. These rules may be expressible in terms of the contents of the Commitment Stores of one or more participants.

Instantiating these rules for different types of dialogue has been a recent research focus. For example, Walton and Krabbe [57.12] presented formal models for persuasion dialogues, and, in joint work with David Hitchcock [57.6], we have proposed the first formal model for deliberation dialogues.

57.3 The Discovery Agora: Formal Structure

With these considerations in mind, we now present our formal structure for the argumentation system for chance discovery, which we have called a *Discovery Agora*. We assume, as above, that the topics of discussion between the participants are represented in some logical language, \mathcal{L} , closed under the usual connectives, whose well-formed formulae are denoted by the lower-case Roman letters, p, q, r , etc. Although the participants may believe different sets of axioms (premises) to be true, we assume they have agreed a set of deductive inference rules. We refer to this logical language and the agreed inference rules as the common logic of the Agora. We further assume a denumerable set of autonomous software agents who participate in the dialogue, each of whom is denoted by \mathcal{P}_i , indexed by $i \in \mathcal{I}$. We assume in this paper that each agent uses the same logical language and rules of inference, and that they differ only in the information they know to be true (i.e. in their premises). Thus, each participant may know part of the story but not the whole story. We further assume that the agents have no inhibitions about sharing information with each other in the Agora.

In this section we present the formal model for the Discovery Agora. We do this, firstly, in Section 3.1, with an informal discussion of discovery dialogues to motivate our formalism, then, in Section 3.2, a formal model of a Discovery Dialogue in the Agora. Section 3.3 presents the rules for a dialogue game in conformance with the formal model.

57.3.1 Discovery Dialogues

We assume the agents in the Discovery Agora are engaged in dialogue. Which of the Walton and Krabbe [57.12] dialogue types mentioned above is appropriate to this domain? The closest type would appear to be an Inquiry dialogue, where participants collaborate to ascertain the truth of some question. However, for the domain of Chance Discovery we want to *discover* something not previously known; the question whose truth is to be ascertained may only emerge in the course of the dialogue. This feature is similar to Deliberation dialogues, where the course of action adopted by the participants may also only emerge in the course of the dialogue itself. The other five types of dialogue all begin with some question or issue for discussion. We therefore believe that the dialogue type appropriate to the Chance Discovery domain is not one of the types of Walton and Krabbe. We will call it a *Discovery Dialogue*.

These dialogues differ from Inquiries in another way. In a pure inquiry, the participants would wish to seek the truth, unadulterated by their preferences or emotional responses. This is unlike a Deliberation, where the preferences or emotions of the participants could play an important part in the selection of an optimal course of action. While the participants in a Discovery dialogue are also seeking truth, there may be many possible truths. It would be

sensible for the participants to filter the truths they discover by what is interesting, novel or important. Discovering risks, for instance, means identifying potential outcomes with significant and deleterious consequences.

How might a dialogue concerning chance discovery proceed? We could imagine a number of elements to such a dialogue. Firstly, there would be agreement (perhaps implicit) about the purpose of the dialogue; this could be, for instance, to assess the risks inherent in some situation or technology. Next there may be the sharing of relevant information known by each of the participants and the pooling of this knowledge to generate new knowledge. For dialogues seeking to discover consequences or risks, there may also be discussion concerning the possible mechanisms by which such risks or consequences could occur. These mechanisms may be chains of possible scientific causality (as in cellular-level biomedical mechanisms) or metaphorical or analogical modes of reasoning. Legal reasoning concerning the potential motives, opportunity and means of a suspect to commit a crime is another example of such mechanisms. Then, once potential discoveries have been articulated in the dialogue, there may be discussion over their attributes. For instance: Are they equally important? What are their relative consequential losses or benefits? etc. This discussion over attributes may in turn lead to consideration of experiments or data collection activities to verify which of competing hypotheses is more likely correct in explaining causal effects. In human dialogues, of course, such discussions do not occur in a linear fashion, but move back and forth between these various elements as the discussion evolves. Our formal model, to be presented next, will include each of these elements and allow for non-linear dialogues.

57.3.2 Model of a Discovery Dialogue

In this section we formalize the discussion just presented. We begin by defining the elements of the discovery dialogue, drawing on the model of an argument proposed by Stephen Toulmin [57.10].

Purpose: The Purpose of a dialogue is the overall issue or issues which motivated the participants to convene and which governs their dialogue. Examples include the risks or the opportunities of some situation. We assume that a discovery dialogue is initiated by one of the participants with a proposed purpose. However, the other participants may not share the same understanding of the dialogue's purpose, and so this needs to be discussed at the outset.

Data Item: A Data Item is a proposition for which at least one dialogue participant has a proof, using premises in that participant's knowledge base and using the rules of inference of the common logic. Participants who articulate data items will be required to present the arguments for them, if requested in the Agora.

Inference Mechanism: An inference mechanism is a warrant which justifies the drawing of a conclusion from one or more data items. Examples of mechanisms include: the rules of deductive inference of the common logic of the participants; default rules; causal mechanisms; metaphors and analogies; legal precedents, etc.

Consequence: A consequence is a claim arising from the application of an inference mechanism to one or more data items.

Criterion: A criterion is an attribute of a data item or a consequence, which may be used to compare one data item or consequence with another. Examples of criteria include: novelty; importance; costs; benefits; feasibility; etc.

Test: A test is a procedure, generally undertaken outside the Discovery dialogue, to ascertain the truth-value of some unknown variable. Examples include: scientific experiments; data collection exercises; information-seeking dialogues.

Conclusion: A conclusion is a full or partial response to the purpose of the dialogue. For example, conclusion could include significant risks identified in the course of the dialogue or interesting opportunities.

With these elements defined, we now present a formal model of the dialogue itself, which moves through ten stages. Our model is similar in approach to the formal model for deliberation dialogues we developed with David Hitchcock in [57.6].

Open Dialogue: Opening of the discovery dialogue.

Discuss Purpose: Discussion of the purpose of the dialogue.

Share Knowledge: Presentation of data items relevant to the purpose, drawing only on each participant's individual knowledge base.

Discuss Mechanisms: Discussion of potential rules of inference, causal mechanisms, metaphorical modes of reasoning, legal theories, etc.

Infer Consequences: Identification of the consequences arising from the application of inference mechanisms to the data items presented by the participants.

Discuss Criteria: Discussion of possible criteria for assessment of the consequences presented.

Assess Consequences: Discussion of the data items and consequences against the criteria previously suggested.

Discuss Tests: Discussion of need for undertaking tests of proposed consequences. If such tests are conducted outside the dialogue, the results may be reported back to the dialogue in a **Share Knowledge** stage.

Propose Conclusions: Proposing one or more conclusions for possible acceptance by the participants.

Close Dialogue: Closing of the discovery dialogue.

Agreement is not necessary in these dialogues unless the participants so desire it. If so, the **Propose Conclusions** stage allows a participant to propose a

conclusion for possible acceptance, and then allows participants to indicate to the Agora their individual acceptance or otherwise. The stages of a discovery dialogue may be undertaken in any order and may be repeated, subject only to certain constraints, which we have articulated in [57.9]. For example, the **Discuss Purpose** must precede any instance of every other stage, excepting the **Open Dialogue** and **Close Dialogue** stages.

57.3.3 Dialogue Game Rules

We now present examples of dialogue-game locutions which, taken together, enable a discovery dialogue to be conducted according to the model just presented. For reasons of space, we do not present all the locutions, nor all the necessary pre-conditions for, and the consequences of, their utterance. We continue to assume that the subject-matter of dialogues can be represented in a propositional language by lower-case Roman letters. We define *questions* as propositions with one or more free variables, and we represent these by lower-case Roman letters suffixed with a question-mark, e.g. “ $p?$ ”. We assume a Commitment Store $CS(P_i)$ exists for each agent P_i . This store contains the various propositions which the agent has publicly accepted, and each store can be viewed by all participants. Entries in the stores are of three sorts: (a) 2-tuples of the form $(type, t)$, where t is a valid instance of type $type$, with $type \in \{purpose, data\ item, inference\ mechanism, consequence, criterion, test, conclusion\}$; (b) 3-tuples of the form (c, t, p) , where c is a consequence, t is a criterion and p a proposition; and (c) 3-tuples of the form (c_1, c_2, t) , where c_1 and c_2 are consequences and t a criterion. The permitted locutions are:

- open_dialogue(P_i, p): Participant P_i proposes the opening of a Discovery dialogue to consider the proposed purpose p . A dialogue can only commence with this move.
- enter_dialogue(P_j, p): Participant P_j indicates a willingness to join a Discovery dialogue to consider the purpose p . All intending participants other than the mover of **open_dialogue(.)** must announce their participation with this move. Note that neither the **open_dialogue(.)** nor the **enter_dialogue(.)** move implies that the speaker accepts that p is the most appropriate formulation of the purpose, only that he or she is willing to enter into a discussion about it at this time.
- propose($P_i, type, t$): Participant P_i proposes proposition t as a valid instance of type $type$, where $type \in \{purpose, data\ item, inference\ mechanism, consequence, criterion, test, conclusion\}$.
- assert($P_i, type, t$): Participant P_i asserts proposition t as a valid instance of type $type$, where $type \in \{purpose, data\ item, inference\ mechanism, consequence, criterion, test, conclusion\}$. This is a stronger locution than **propose(.)**, and results in the tuple $(type, t)$ being inserted into $CS(P_i)$, the Commitment Store of P_i . For certain types, utterance of this locution

leads to the speaker having a *burden of defence*, i.e. to provide supporting arguments or evidence for the assertion if so requested by another participant.

- query(P_j , propose(P_i , $type$, t)): Participant P_j requests participant P_i to provide a justification for his proposal of t as a valid instance of type $type$, where $type \in \{data\ item, consequence, test\}$, and where $j \neq i$. Similarly, a participant may query an assertion with the command **query**(P_j , **assert**(P_i , $type$, t)). In response to either query, P_i must defend his proposal or assertion statement with an utterance of **show_arg**(.).
- show_arg(P_i , $type$, t , A): Participant P_i presents an argument A for proposition p which is type $type \in \{data\ item, consequence, test\}$. In the case of *data items*, the argument A is a proof from premises in the knowledge base of participant P_i and using deductive inference rules in the common logic of the dialogue. In the case of *consequences*, the argument A comprises one or more sequences of the form (D, I, C) , where D is a set of *data items*, I is an inference mechanism and C is a consequence which can be drawn from D using I ; all elements of this set must previously been articulated in the Agora by means of appropriate **propose**(.) or **assert**(.) locutions. In the case of *tests*, the argument A also comprises one or more sequences of the form (D, I, C) , where D is a set of *data items*, I is an inference mechanism and C is a consequence which can be drawn from D using I , but these need not have been previously presented in the dialogue.
- assess(P_i , c , t , p): Participant P_i asserts that when consequence c is assessed on the basis of criterion t , one may conclude proposition p . This locution inserts (c, t, p) into $CS(P_i)$.
- compare(P_i , c_1 , c_2 , t): Participant P_i asserts that consequence c_1 is better or equal to consequence c_2 when they are compared on the basis of criterion t . Each of c_1, c_2 and t must previously been articulated in the Agora by means of the appropriate **propose**(.) or **assert**(.) locutions. This locution inserts (c_1, c_2, t) into $CS(P_i)$.
- recommend(P_i , *conclusion*, a): Participant P_i proposes proposition a as a recommended conclusion. This locution inserts $(conclusion, a)$ into $CS(P_i)$.
- accept(P_j , *locution*): Participant P_j indicates agreement with the prior locution, *locution*, uttered by another participant. If the prior locution resulted in a change to that speaker's commitment store then the **accept**(.) locution similarly alters $CS(P_j)$.
- contest(P_j , *locution*): Participant P_j indicates disagreement with the prior locution, *locution*, uttered by another participant. The **contest**(.) locution is the obverse of **accept**(.) and has no impact on $CS(P_j)$.
- retract(P_i , *locution*): Participant P_i indicates retraction of her prior utterance of the locution *locution*. If the prior locution resulted in an insertion into $CS(P_i)$, then the **retract**(.) locution deletes it.

$\text{withdraw_dialogue}(P_i, p)$: Participant P_i announces her withdrawal from the Discovery dialogue to consider the governing question p .

We now demonstrate that the dialogue game locutions we have defined can be used to undertake a Discovery dialogue in accordance with the formal model we have proposed.

Proposition 1 Each of the ten stages of the formal model of discovery dialogues presented in section 3.2 can be executed by judicious choice of these dialogue-game locutions.

Proof. We consider each stage in turn:

1. A dialogue opens with the locution **open_dialogue**(P_i, p) and at least one utterance of **enter_dialogue**(P_j, p), with $j \neq i$.
2. The Discuss Purpose stage consists of utterances of **propose**(.), **assert**(.), **accept**(.), **contest**(.) and **retract**(.), in each case with the type *purpose*.
3. The Share Knowledge stage consists of utterances of **propose**(.), **assert**(.), **accept**(.), **query**(.), **show_arg**(.), **contest**(.) and **retract**(.), in each case with the type *data item*.
4. The Discuss Mechanism stage consists of utterances of **propose**(.), **assert**(.), **accept**(.), **contest**(.) and **retract**(.), in each case with the type *inference mechanism*.
5. The Infer Consequences stage consists of utterances of **propose**(.), **assert**(.), **accept**(.), **query**(.), **show_arg**(.), **contest**(.) and **retract**(.), in each case with the type *consequence*.
6. The Discuss Criteria stage consists of utterances of **propose**(.), **assert**(.), **accept**(.), **contest**(.) and **retract**(.), in each case with the type *criterion*.
7. The Assess Consequences stage consists of utterances of **assess**(.), **compare**(.), **agree**(.), **contest**(.) and **retract**(.).
8. The Discuss Tests stage consists of utterances of **propose**(.), **assert**(.), **accept**(.), **contest**(.) and **retract**(.), in each case with the type *test*.
9. The Propose Conclusions stage consists of the **recommend**(P_i, action, a) locution, possibly followed by utterances of **accept**(P_j, action, a).
10. Participants may exit a dialogue, by means of the **withdraw_dialogue**(P_i, p) locution, at any time. The dialogue itself closes once the second-last participant utters this locution. (EOP)

In addition to defining the permitted locutions, we have specified commencement, combination, commitment and termination rules for this game [57.9]. These rules have been specified to accord with principles of joint mutual inquiry between consenting participants proposed by Hitchcock in [57.5].

57.4 Conclusion

This paper has proposed a formal argumentation system for chance discovery in domains where knowledge is distributed between autonomous agents. Our approach has led us to propose a new type of dialogue, which we call a chance discovery dialogue, for arguments in this domain. We have proposed a formal model for the conduct of discovery dialogues, and presented the locutions and rules for a dialogue game undertaken in accordance with this model.

We are currently considering a number of further research lines, in particular the question of whether discovery dialogues can be automated. We are exploring the use of evolutionary computational approaches to enable fully automated dialogues to be conducted. For example, it may be possible to use a genetic algorithm to generate candidate discoveries which are then processed through the dialogue-game described above. Those which are accepted by the participants to the discussion may be considered the fittest survivors and so form the basis for a subsequent generation of discoveries, which are discussed in subsequent dialogues.¹

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58. Methodological Considerations on Chance Discovery

Helmut Prendinger and Mitsuru Ishizuka

Department of Information and Communication Engineering
Graduate School of Information Science and Technology
The University of Tokyo
7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
{helmut, ishizuka}@miv.t.u-tokyo.ac.jp

This paper investigates the methodological foundations of a new research field called *chance discovery*, which aims to detect future opportunities and risks. By drawing on concepts from cybernetics and system theory, it is argued that chance discovery best applies to open systems that are equipped with regulatory and anticipatory mechanisms. Non-determinism, freedom (entropy) and open systems property are motivated as basic assumptions underlying chance discovery. The prediction-explanation asymmetry and evaluation of chance discovery models are discussed as fundamental problems of this field.

58.1 Introduction

Several researchers within the Knowledge Discovery in Databases (KDD) community (e.g., Ohsawa [58.9]) questioned whether the methods of this research field are able to find what they call ‘chances’. Chances refer to phenomena that might have a (high) impact to the scientific (and human) society or an enterprise in the future. High impact is intended to have two complementary readings: on the one hand it refers to *opportunities*, i.e., the possibility to bring about desirable effects; on the other it refers to *risks*, i.e., possible threats to an enterprise or society. The notion of *chance discovery* has been coined to cover both aspects. Finding future features is seen in contrast to prediction (e.g., in KDD), the scientific activity to derive phenomena that appear at some future time point. By contrast, chance discovery explicitly integrates human initiative into the discovery process.

Procedurally, chance discovery can be seen as a two-step activity. The first step involves a actual discovery of a certain phenomenon. The second step suggests actions taken as a consequence of a designated phenomenon (chance), which is often called (*chance*) *management* and involves supportive measures in the case of opportunities as well as preventive measures in the case of risks.

Although there might be some interesting interactions with the *probabilistic* notion of chance, this reading is not intended in chance discovery. Likewise, chance discovery is not concerned with discovery *by* chance, such as the discovery and isolation of penicillin by Alexander Fleming.

We will discuss the following topics. In the following section, the notion of *open system* is explicated in terms of cybernetics and system theory, and the possibility of prediction is discussed for both nature and open systems. The next section discusses chance discovery in open systems. In particular, the notion of ‘anticipation’ is introduced as a mechanism for chance discovery and exemplified by examples. After that, we explicate notions underlying the possibility of chance discovery: uncertainty and freedom. In the following section, chance discovery is contrasted with KDD. Finally, we briefly discuss and conclude the paper.

58.2 Nature vs. Open Systems

To clarify the application field of chance discovery, we draw a broad distinction about the object of investigation: nature vs. open systems [58.12]. Whereas nature is governed by natural laws, open systems are typically modeled abstractly by cybernetics [58.1] and system theory [58.16]. Examples of open systems include ‘living’ systems such as human beings, scientific communities and companies, and artificial (or technical) systems, e.g., cars and power plants. Both kinds can be described by the following system-theoretical ($S1 - 2$) and cybernetical ($C1 - 2$) features (Schurz [58.12]):

- $S1$ Open systems are physical ensembles placed into an environment significantly larger than themselves. There is a continuous exchange of energy between system and environment. The environment may satisfy the system’s ‘needs’ (see $C1$) or ‘destroy’ the system (see $C2$).
- $S2$ Open systems preserve a relative identity through time, called their *dissipative* state.
- $C1$ The identity in time is abstractly governed by *ideal states* (or norm states) which the system tries to approximate, given its actual state.
- $C2$ Regulatory mechanisms compensate disturbing influences of the environment, i.e., they continuously try to counteract influences that move the system apart from its ideal state. If the external influences exceed a ‘manageable’ range, the system is destroyed.

For our present discussion, the regulatory mechanisms of open systems are of central concern since they can actively interfere with the evolution of the system, by bringing about (an approximation of) the ideal state, or avoid the destruction of the system. Later, we will introduce a new kind of mechanism, called ‘anticipation’, that has the potential to significantly influence the systems evolution and most closely corresponds to our notion of chance discovery.

58.2.1 Prediction in the Natural Sciences

Nature is governed by the laws of physics, e.g., Newton’s second axiom (the *total force* law). Obviously, in the physics domain there is no way to influence

the natural laws. So even if we predict a phenomenon of high impact to society, such as a giant meteorite approaching the earth at high speed, all we can do is to evacuate the area the meteorite is predicted to hit.

Since it is not possible to change the course of nature, chance discovery here means to take appropriate (supportive, preventive) measures to minimize damage or maximize benefit.

58.2.2 Prediction in Open Systems

Open systems are characterized by system laws. Schurz [58.12] argued that we are *theoretically unable* to determine the exact numerical values corresponding to system laws, because the systems are open and hence described by nonlinear differential equations. In the extreme case, if external influences exceed the manageable (or critical) range of the system, nonlinear dynamics becomes effective and leads to *chaotic* behavior. Due to the sensitivity of open systems to external influences, prediction is a difficult matter. Below we will argue that in open systems, the activity of regulatory mechanisms is of major importance, rather than prediction.

58.3 Chance Discovery in Open Systems

58.3.1 Enterprise Example

Let us first give an illustrative example. *Enterprises* (companies) can be viewed as open systems that consist of subsystems (branches, sections, and individuals), and operate in an environment, the so-called ‘economic market’. This environment typically satisfies the companies ‘needs’, e.g., customers demand the company’s products. Under unfortunate circumstances, the company may run into the risk of being ‘destroyed’, e.g., by the appearance of a strong competitor (cf. *S1*). In spite of that, companies preserve identity through time (cf. *S2*). A company constantly tries to approximate an ideal state where, for instance, increasing profits are made and the economic situation of the company is stable. This is achieved by the company’s subsystems that perform certain functions, including good production and distribution, and marketing (cf. *C1*). A company is typically confronted with a multitude of ‘disturbing’ influences in the form of, e.g., cheaper and better products of other companies and changing customer needs. At this point, the regulatory mechanisms of the company come into force, e.g., to lower production costs by increasing the efficiency of the production cycle. It is well-known that companies go bankrupt when a critical range is exceeded (cf. *C2*).

58.3.2 The Limits of Regulatory Mechanisms

Regulatory mechanisms are the system’s means to approximate the system’s ideal state. Those mechanisms are mainly active to compensate disturbing

influences by *reacting* to them. Although regulatory mechanisms are usually able to guarantee the identity of an open system, they come into force only if confronted with ‘threats’ from the environment. For instance, if a company’s sales decrease, the CEO might decide to shrink the company, thereby making a number of people unemployed.

In the next section we will argue that in addition to regulatory mechanisms, open systems need mechanisms of *anticipation* to cope with the complexities and influences of the environment.

58.3.3 Chance Discovery as Anticipation

In a recent report to the *Club of Rome*, Botkin *et al.* [58.2] introduce the term “anticipation” as a key feature of innovative learning that emphasizes human initiative. It is described as follows [58.2, p. 25]:

[...] anticipation is not limited to simply encouraging desirable trends and averting potentially catastrophic ones: it is also the “inventing” or creating of new alternatives where none existed before.

Anticipation is contrasted to prediction, since the former focuses on the *creation* of possible and desirable futures, and plans to bring them about. The notion of anticipation shares the intuition of Alan Kay’s phrase “The best way to predict the future is to invent the future”.

Promotion. In philosophy of science, the term “self-fulfilling prophecy” describes situations such as the following. Newspapers write articles about the morbidity of a bank institute. As a consequence, many customers of this institute withdraw their money and other commitments. In effect, the bank institute gets into serious trouble. A recent ‘real’ example is the success of the so-called *New Economy* (internet and telecommunication related shares). Since many people believed in its success, it became a great success (at least for some time).

Chance discovery as anticipation in this context means the promotion of a trend desired by New Economy companies. As a result of promotion, the desired trend could be effected. Similar forms of promotion are daily practice in companies: certain products are advertised with the hope that they actually trigger a desire in customers. The detection of ‘latent’ customer desires will be briefly discussed in the next section.

Collaboration. In business there is a lot of talk about ‘mergers’. Collaborations are also seen in scientific research programs. We will briefly describe the field of Quantum Computation.

Deutsch [58.3] is reported to be the first to explicitly ask whether it is possible to compute more efficiently on a quantum computer. For a long time, this possible collaboration of quantum theory (physics) and artificial intelligence (computer science) remained a curiosity. However, there are already some indications of ‘killer applications’ for quantum theory. For instance,

Spector *et al.* [58.13] report on problems that take polynomial time on a quantum computer but exponential time on a classical computer.

In academics, possibilities for collaborations are ubiquitous, and sometimes realized, e.g., in genome analysis, artificial intelligence and biology collaborate. What might chance discovery as anticipation mean here? In particular, how can we anticipate the success of a certain kind of collaboration? We cannot provide a working methodology here. In the case of quantum computation, the chance was ‘discovered’ by Feynman [58.5] who observed that classical systems cannot effectively model quantum mechanical systems. This observation suggests that computers based on the laws of quantum mechanics (instead of classical physics) could be used to efficiently model quantum mechanical systems, and possibly even solve classical problems such as database search in a highly efficient way.

Given that Quantum Computation will indeed be successful, how could we have known 10 years ago? One method would be to track the history of ‘conjectures’ (ideas, observations) formulated by various insightful researchers, and evaluate their feasibility in the light of current knowledge in possibly quite different research areas. The availability of huge amounts of information on the Web might facilitate such an endeavor.

58.4 Chance Discovery, Uncertainty, Freedom

One of the tacit assumptions underlying chance discovery is that the future is uncertain, and hence there is freedom to change its course of action. For the sake of argument, assume the opposite, i.e., the world history evolves deterministically. Obviously, under this artificial assumption, chance discovery (in our sense) is not possible as there are no choices.

58.4.1 Freedom

Following [58.15], we propose entropy as the measurement of freedom. Specifically, the measurement of freedom is phenomenologically rather than procedurally oriented. The freedom of a set A of alternatives is measured by the entropy H of the actual chosen proportions, i.e.,

$$H(A) = - \sum_{i \in A} p_i \log p_i$$

where \log is to the base 2, $p_i \geq 0$ and if $p_i = 0$ then $0 \log 0 = 0$. Accordingly, we may say that chances exist if there are (almost) evenly distributed alternatives. Consider the following situations (A) and (B).

- (A) There are three sellers with (approximately) 30% market share.
- (B) There are two sellers, one has 75%, the other has 25% market share.

Situation (A) has more freedom than situation (B), since a market with one dominant provider has low entropy. The more interesting notion here is freedom of successive states for a number of time periods. For instance, a market with 100% customer loyalty is not free.

58.4.2 Explaining versus Predicting

Let us recall the aforementioned open system situation, that features a high degree of uncertainty, and formulate it as a problem for chance discovery and chance management (CD&CM). In the following, M stands for a CD&CM model (or theory).

- Assume as given a model M that explains why a particular phenomenon X turned out to be a chance (opportunity or risk), as observed by its high (positive or negative) impact.
- Given a phenomenon of type X , can we employ M to predict high impact under comparable circumstances?

Of course, the notions of *phenomenon of type* and *comparable* warrant further explication. In order to clarify the problem, consider the case of simple unstable or chaotic systems that support explanations without predictive value. Assume an ideal ball exactly on top of another ideal ball. Here, we cannot predict in which direction the ball will roll down, but after it rolled down, we can explain it by an unmeasureably small disturbance in the direction in which the ball rolled down [58.11].

Thus, the ‘explanation vs. prediction’ problem raises the fundamental question about which systems support the predictive use of chance discovery results. Straightforward answers seem to be ruled out by the fact that human initiative is essential to take opportunities or avoid risks, and the complexity of systems such as the web or financial markets.

As a more realistic example, consider Ogawa’s [58.7] ILE (Information of Liability and Equity) measure that identifies risk factors that eventually lead to bankruptcy. Specifically, ILE *explains* bankruptcy. The crucial question, however, as in science is whether ILE can *predict* bankruptcy. If ILE has predictive value, the impact of preventive measures can be proven. Given the theoretical result about the infeasibility of prediction in open system, we are left with a probabilistic notion of prediction.

58.5 Scientific Evaluation of Theories

A basic question about scientific theories is how they can be evaluated. Following Popper [58.10], a theory is corroborated (or validated) if it predicts a phenomenon that is actually observed, while it is falsified when a phenomenon is observed that contradicts the observation. Note that a theory can

never be verified by a finite set of observations. The situation for CD&CD models is complicated for the following reason.

Triple-theory Problem. Whether the discovery of a potential chance turns into a positive result is dependent on three factors:

1. The designated phenomenon was a ‘real’ chance, i.e., chance discovery is successful.
2. The chosen measures were appropriate, i.e., chance management was successful.
3. The predictions about the world for the associated time span of CD&CD were sufficiently accurate.

The triple-theory problem refers to the practical problem that in order to validate (or falsify) a CD&CM model, three sub-theories have to be successful. If all of them are successful, observed by the positive result, the model is corroborated. However, in the case of a negative result, we cannot simply say that the designated phenomenon was no chance, because we either did not choose appropriate (supportive or preventive) measures to bring about the positive outcome or our predictions about the boundary conditions for the positive outcome have been false.

From a methodological point of view, the triple-theory problem puts serious doubts whether we might be able to evaluate CD&CM models scientifically. Due to the very nature of the open systems, reproducibility of results is infeasible.

58.6 Chance Discovery vs. KDD

Fayyad *et al.* [58.4] characterize Knowledge Discovery in Databases (KDD) as

[...] the nontrivial process of identifying valid, novel, potentially useful, and ultimately understandable patterns in data.

The discovery goal in KDD can be divided into a descriptive and a predictive part. In *description* the system seeks for patterns (or models) in order to present them to the user in an intelligible way; in *prediction* the system finds patterns so that the future behavior of some entity can be predicted. There exist a number of established (mostly statistical) data mining methods to achieve those goals, such as classification, regression, clustering, summarization, dependency modeling, and change and deviation detection [58.4].

Chance discovery may use the knowledge extracted by data mining methods to detect future features. For instance, by Web usage mining, i.e., the clustering of Web users based on their browsing activities, potential customer groups can be identified, and specifically addressed by companies. Here the interplay of data mining—describing correlations between users’ interests—and chance discovery—actively promoting a possibility—is of crucial importance.

One may ask whether, e.g., data mining already *is* a form of chance discovery. Our answer is “no”. Data mining can summarize or predict trends, but leaves out the rôle of human interference. Anticipation as a mechanism of an open system, on the other hand, ‘matches’ a desired (or predicted) trend with the system’s goals (typically human ‘desires’) and accordingly takes supportive or preventive measures.

Another way of contrasting Chance Discovery and KDD is as follows. Whereas KDD tries to detect most likely trends in data, Chance Discovery aims at finding data that do not match likely patterns but indicate interesting phenomena not yet exploited and bearing potential of future trends. However, currently there exist no serious analysis to distinguish those high-potential phenomena from ‘noise’ in data. Basically, this means that exceptions can be equally informative as highly probable regularities. As an example, consider the following. Humans that are infected with *plasmodium vivax* are very likely to contract malaria. However, some people do not. In KDD terms, those people are ignored since they do fall under the likely case (contracting malaria). It turned out that it is due to a special genetic constellation that some people have a strong protection against malaria. In Chance Discovery terms, the explanation of those people’s resistance against malaria is a chance for a significant scientific discovery.

58.7 Discussion and Conclusion

In this paper, we explicate our take on a new research area called ‘Chance Discovery’. The notion of ‘open system’, as characterized in cybernetics and system theory, serves as a framework to embed the activity of Chance Discovery. In particular, anticipation is introduced as a mechanism that may perform the rôle of detecting chances in open systems. The anticipating mechanism is explained in the context of promotion in New Economy and collaboration in the Quantum Computation research programme. Chance Discovery is contrasted to KDD and mutually beneficial aspects are explained. We identify human initiative as a distinguishing feature of Chance Discovery (as opposed to KDD), e.g., to actively initiate and foster a trend by promotion or to actively explore the (practical) feasibility of a theoretical conjecture.

Unlike the practical methods for data mining, we only described a methodology for Chance Discovery. A method for Chance Discovery might analyze ‘success stories’, i.e., cases where features of high impact for the future were successfully identified and accordingly promoted by human initiative. This retrospective analysis might be framed and processed by means of *KeyGraph* [58.8], a smart indexing method originally developed for information retrieval.

Recently, McBurney and Parsons [58.6] proposed principled methods to discover chances based on dialogue games. In the context of e-commerce systems, Stolze and Ströbel [58.14] investigate interviews with buyers in order

to identify their (implicit) needs. We believe that the theoretically founded methods will have the greatest impact on the field of Chance Discovery.

In this paper, we mainly focussed on the epistemological aspect of chance discovery. However, the discovery of potential opportunities and risks seems to be intimately connected to questions about *human values*, what should be the case and what should not be the case. Obviously, there are no opportunities or risks *per se*, they are only given with respect to certain values and associated goals of humans. To give drastic example, the detection of a future earthquake is not only a high risk for people living in a particular region, it is also an opportunity for certain organizations to take advantage of the chaos following the earthquake.

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59. Future Directions of Communities on the Web

Naohiro Matsumura^{1,2}, Yukio Ohsawa^{2,3}, and Mitsuru Ishizuka¹

¹ University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo, Japan
matsuo@miv.t.u-tokyo.ac.jp

² PRESTO, Japan Science and Technology Corporation,
Tsutsujigaoka 2-2-11, Miyagino-ku, Sendai, Miyagi, 983-0852 Japan

³ University of Tsukuba, Otsuka 3-29-1, Bunkyo-ku, Tokyo 113-0012, Japan

Discovering new topics which cover new items, problems, and ideas (e.g., mobile phone, global warming, human genome project, etc) is truly profitable, important, and interesting for us. For instance, 1. Companies producing 'mobile phones' have made large profits by the great sales, 2. The awareness of 'global warming' has improved the environment of the earth by regulating exhaust emissions, 3. Fatal illnesses might be conquered by the human genome project. However, since we cannot completely decode the world surrounding us, we cannot know the topics and their mechanisms in advance. Considering this situation, these phenomena could be a big chance for our activities. In this paper, we describe our approach for discovering the future directions of communities on the web to detect chances.

59.1 Introduction

Often, a new topic suddenly becomes popular although it seems insignificant at first sight. The Tipping Point describes this kind of phenomenon where a 'little' thing can make a big difference[59.1]. We are deeply confused by changes that happen suddenly. However, since we cannot completely decode the world surrounding us, we cannot know the chances and their mechanisms in advance. Considering this situation, the Tipping Point could be a big chance for our activities. We understand 'topics' in the broad sense that cover new items, problems, ideas, and so on. Below, we show you some recent examples of new topics:

Mobile Phone: Considering the context of the appearance of mobile phones, there were essentially two factors. First, mobile phones conquered the inconvenience of beepers that people had to find a public phone when a beeper rang. Second, mobile phones were equipped with the functions of the Internet and E-mail services. Due to the synergy effects of these factors satisfying our needs, mobile phones began to get popular.

Global Warming: The awareness of global warming realized the collaboration of automobile and environmental preservation communities, and consequently brought about hybrid automobiles which have minimal exhaust emissions for preserving the environment of the earth.

Human Genome Project: Many researchers in the field of artificial intelligence, biology, and medical science are collaborating on the human genome project to analyze the human genome and to reveal its effects. The human genome project is getting into the limelight because we expect the conquest of fatal illnesses.

In many cases, these topics were born when new collaborations of existing topics satisfy our potential needs or demands. Although the hidden factors might only be 'submerged' in the human mind, we believe that a few signs can be mined from a database reflecting human's thought. For this purpose, the web is an attractive information source for its sheer size and sensitivity to trends. The web consists of an abundance of communities[59.2, 59.4], each corresponding to a cluster of web pages sharing common interest. However, the communities are not independent but are related with each other in varying degrees. From this point of view, we are expecting the relations of communities might show the future directions of communities, and suggest the potential needs or demands.

In this paper, we describe our approach for discovering the future directions of communities by exploring the link structure of the web. We have implemented a prototype system named *ChanceFinder* that visualizes the future directions of communities and ranks promising web pages and links. Empirically, *ChanceFinder* showed some interesting directions for some topics.

The rest of this paper is organized as follows. In Section 59.2, we introduce related researches, and the process of *ChanceFinder* is described in Section 59.3. The experiments are discussed in Section 59.4, and finally we conclude this paper in Section 59.5.

59.2 Related Researches

Our research consists of two parts: the discovery of communities, and the discovery of relations among these communities. In this section, we introduce researches related to these two processes.

59.2.1 Discovery of Communities

A community on the Web is defined as a cluster of web pages which share common topics. However, there are many ways to detect the clusters.

For example, Broder et al.[59.2] reported on an algorithm of clustering web pages based on the contents. This approach can be applied not only to hyper-text(e.g., web pages) but also plain-text. However, indexing web pages accurately is difficult because the contents of web pages are not always meaningful.

In contrast to the content-based approach, links in web pages can be reliable information because they reflect human judgment. Botafogo and Shneiderman[59.3] proposed an idea for abstraction called *aggregate* based on graph theory. Their algorithm removes 'indics'(nodes with high number of out-links) and 'references'(nodes with high number of in-links) iteratively to clear the graph. However, removed nodes often become very important elements to understand the web. On the other hand, Kumar et al.[59.4] defined a community on the web as a dense directed bipartite subgraph, and discovered over 100,000 communities. However, the scale of subgraphs depends on its parameters. This implies the difficulty in detecting communities from the web since the communities are often somewhat related with each other. We think the relations show the future directions of these communities.

As another use of links, Kleinberg[59.5] and Brin and Page[59.6] used the link structures for ranking web pages. Their main idea was based on mutually reinforcing that the more a web page is referred, the more authoritative the web page becomes, and the more authoritative a web page becomes, the higher the web page ranks. The highly ranked web pages tend to be the representative web pages of communities.

59.2.2 Discovery of Future Directions

In the broad sense, future directions refer to meaningful relations among communities in various scenes. Focusing on WWW, Matsumura et al.[59.8] discovered promising new topics on the web by visualizing new combinations of communities sharing common topics. Ohsawa et al.[59.11] proposed KeyGraph, which is an algorithm for extracting assertions based on co-occurrence graph of terms from textual data. KeyGraph visualizes the relations between assertions and foundations to help us understand potential needs or demands. Accordingly, KeyGraph can be applied to show the future directions of textual data.

As for the human relations in communities, Kautz et al.[59.9] created REFERRAL WEB, a social network graph designed to find an expert who is both reliable and likely to respond to the user. Also, Foner et al.[59.10] described a matchmaker system named Yenta for finding people with similar interests and introduce them to each other. Both systems reveal the potential relations between individuals, therefore, they show the future directions of individuals. Maarek et al.[59.12] embodied WebCutter which outputs a tailored map of the web according to the user-specified interests. The map is one of the suggestion of the future directions of the user because it shows essentially related web pages.

59.3 Future Directions of Communities

For the discovery of new topics on the web, we aim to discover the future directions of communities and to understand the potential needs or demands. In this section, we first represent the overview of our idea, and then describe our approach in detail.

59.3.1 How to Discover the Future Directions?

Our approach for discovering the future directions is based on link analysis because links can be more reliable information than terms (see 59.2.1). The outline of our process consists of five phases as follows:

Phase1. Collect web pages.

Phase2. Discover communities on the web.

Phase3. Discover established relations among the communities.

Phase4. Discover future directions among the communities.

Phase5. Visualize the future directions.

The accurate definition of a community on the web is an essential problem by itself. In Phase1, following Kumar's definition [59.4], we expediently define a simple bipartite graph as a community where a community consists of a much cited web page and its surrounding web pages. Next, we focus on the property of the web that communities are often somewhat related with each other because a web page often belongs to some communities. In our view, the relations may include established(well-known) relations as well as the future directions of these communities. The degree of relation among two communities can be measured by the number of web pages included in both the communities. This idea is based on the co-citation concept originated in

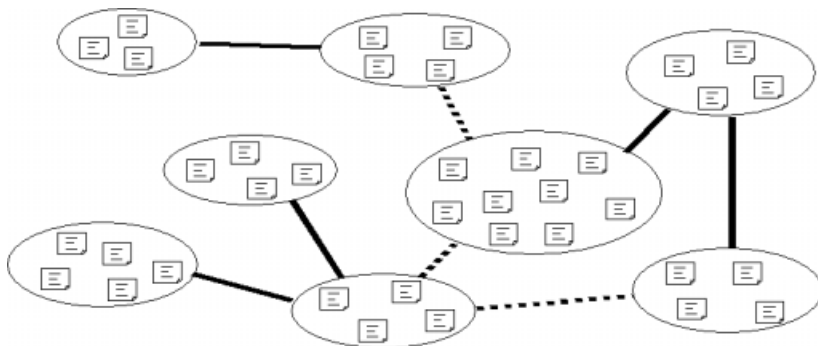


Fig. 59.1. An overview of the web. Each cluster corresponds to a community sharing common interest. Communities are often share the same interest with each other. Here, solid lines mean established relations and dotted lines show future directions.

the bibliometrics[59.7]. In this way, we regard strong relations as established relations in Phase2, and weak relations as the future directions in Phase3. Our idea is graphically shown in Fig. 59.1. Considering the fact that an established link arises only when a future direction grows, focusing on future links is useful for understanding where the changes happen.

59.3.2 The Detailed Process

Here, we describe our approach sketched in 59.3.1 in detail.

Phase1. Preparations: First of all, let a user decide a target area/topic which s/he want to explore the future directions. Then, source web pages D are collected by using Google ¹. Here, the first 500 web pages of Google's output for the query are downloaded.

Phase2. Discover Communities: For surveying the picture of communities by discovering the future directions among communities, we make use of only centered web pages in communities instead of all the web pages. The centered web page named as **core-page** is extracted as follows.

1. Count the frequency of links included in D .
2. Regard the top N_1 links C as the 'core-pages' of communities.

Phase3. Discover Established Relations: Measure the relations among core-pages by counting the number of co-citations, and regard strong relations as established links. The process is as follows.

1. For every pair of two core-pages in C , count the number of links included in both the core-pages.
2. Regard the top N_2 pairs as established links L_1 (solid lines in Fig. 59.1).

Phase4. Discover Future Directions: Measure the relations among core-pages by counting the number of co-citations, and regard weak relations as future links. The process is as follows.

1. For every pair of two cores in C except for L_1 , count the number of links included in both the cores.
2. Regard the top N_3 pairs as future links L_2 (dotted lines in Fig. 59.1). The movement of communities are shown by established and future relations. Therefore, future directions are expressed by the combination of these two kinds of relations.

Phase5. Visualization: Core-pages and its relations(C , L_1 , and L_2) are visualized into 2-dimensional interface to piece out the connections of communities and to understand the potential needs or demands.

¹ Google is a search engine to which Brin and Page's algorithm[59.6] is applied. Google is available at <http://www.google.com/>.

59.4 Experiments and Discussions

We have implemented a prototype system named *ChanceFinder* on a Sun Enterprise450 with perl5 and Perl/Tk. ChanceFinder visualizes future directions. In this section, we show three experiments of ChanceFinder with $N_1 = 30$, $N_2 = 29$, and $N_3 = 10$, and discuss them (These experiments were done on 17th of January in 2001).

59.4.1 Future Directions of Portal Sites

The output of ChanceFinder for input query 'Portal Site' is shown in Fig. 59.2. Each node stands for a community, and especially each white node represents a core with many future links. Strong relations of communities are expressed by thick lines (established links), and promising future direction of communities are shown by thin lines (future links). The URL below each node shows the core of each community. Considering the near future, future links might change into established links or disappear. In either event, we should focus on only future links to predict the future. That is to say, the output shows the present and future map of communities.

We can perceive three clusters in Fig. 59.2. The lower right-hand cluster is constructed by 4 major portal sites: 'Yahoo!', 'Infoseek', 'Excite', and 'Lycos'. The cluster is considered to be matured since every node links to each other by established links, and this assumption actually matches well accepted norms.

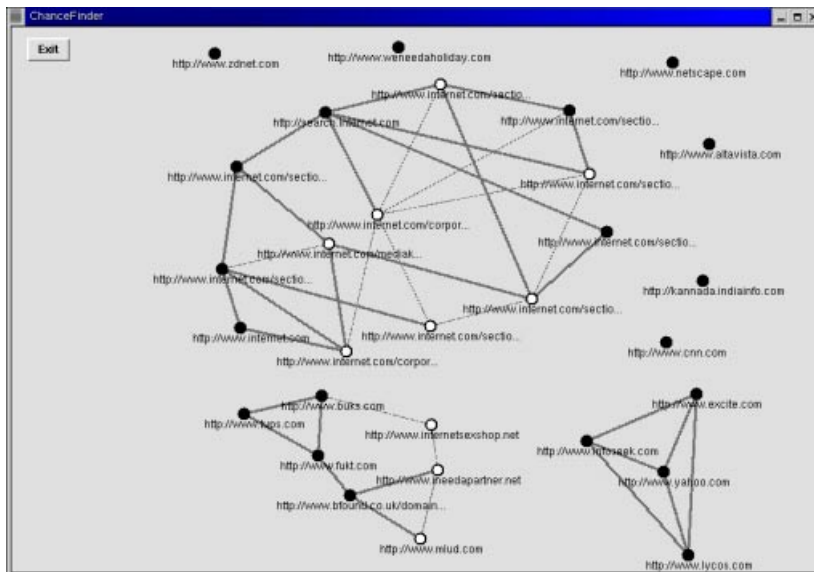


Fig. 59.2. An output of ChanceFinder for input query 'Portal Site'.

All the communities in the lower left-hand cluster are strongly related to 'Bfound.co.uk' which is a company conducting web design, internet solutions, and e-commerce. This cluster seems to be a community in early development.

The upper middle cluster consists of web pages belonging to 'internet.com' communities. According to the 100hot.com² which is the Web's leading ranked directory where the rankings are based on the Internet habits of more than 100,000 Web surfers each month, internet.com got 77th in the same date as the experiment. This means that 'internet.com' is not a major portal site at present. However, we can see that the cluster is in energetic development because the cluster is composed of 13 communities, 17 established links, and 8 future links.

59.4.2 Future Directions of Book Site

From the output of ChanceFinder for input query 'Book Site' shown in Fig.59.3, we can easily recognize one big cluster and two tiny clusters.

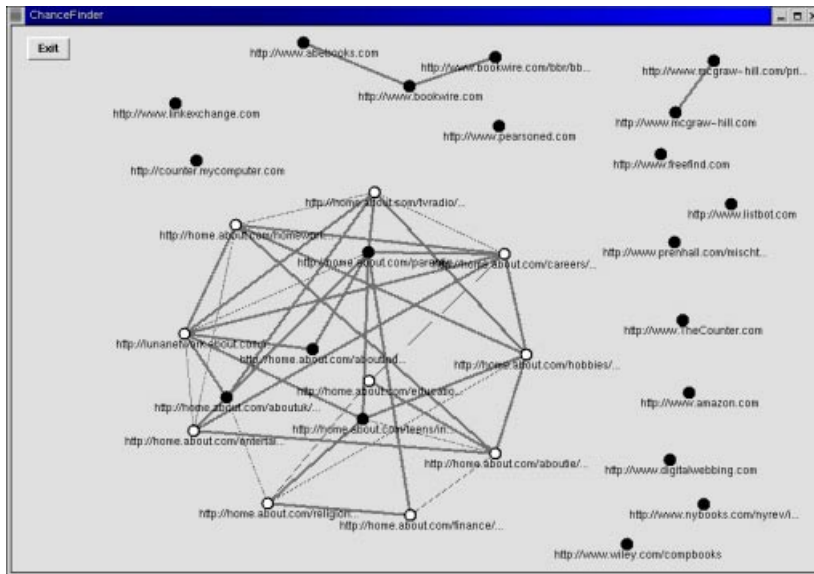


Fig. 59.3. An output for 'Book Site'.

The upper-middle cluster is composed of two 'bookwire.com' sites and one 'abebooks.com' site. The former is the book industry's most comprehensive and thorough online information source, and the latter is the world's largest source of out-print books. That is, this cluster shows information sources of books.

² <http://www.100hot.com>

The upper-right cluster includes two communities of 'mcgraw-hill.com' sites. These sites look like tiny cluster at first sight, but these are the web page of McGraw-Hill company which is a time-honored publisher founded in 1909. Therefore, this cluster means a well established community.

The largest cluster comprises 14 About.com communities. The cluster seems to be already connected densely since it has 25 established links, and 11 future links. In fact, according to the survey on 'Portals leapfrog up Media Metrix chart of the Web's top sites' in December 1999, About.com is described as follows ³:

Excite@Home Corp., NBC Internet Inc. and About.com Inc. are on the rise, according to the latest traffic numbers from Internet measurement firm Media Metrix Inc.

However, About.com seems to be a minor web site in the area of 'Book Site' yet (About.com does not appear in the rankings of 100hot.com). For these reasons, About.com is considered to be struggling to expand the influences, and this consideration can be read from Fig. 59.3.

Interestingly, 'amazon.com', the most famous and giant book site exists alone in the middle-right in Fig. 59.3. This implies that almost all the communities rival each other, and Fig. 59.3 clearly shows this situation.

59.4.3 Future Directions of Artificial Intelligence

The output for input query 'Artificial Intelligence' is shown in Fig. 59.4. Viewing Fig. 59.4, we can recognize only one big chunk of communities where 20 communities, 28 established links, and 11 future links are densely connected. Fig. 59.4 is essentially different from above two examples in the point that the cluster in Fig. 59.4 consists of different communities. This may show the maturity of the area of 'Artificial Intelligence'. If this assumption is true, we must seek a new area which collaborates with 'Artificial Intelligence' to create future directions.

59.5 Conclusions

In this paper, we first insist on the importance of discovering new topics. Then, we describe the idea of discovering future directions of communities by chaining primitive communities to understand potential needs or demands. Through some experiments and their evaluations, we show that ChanceFinder certainly shows the relations of communities. However, we expect that whether the relations really become the future directions depends on the user's vision or imagination based on accurate information.

³ <http://www.zdnet.com/zdnn/stories/news/0,4586,2424687,00.html>

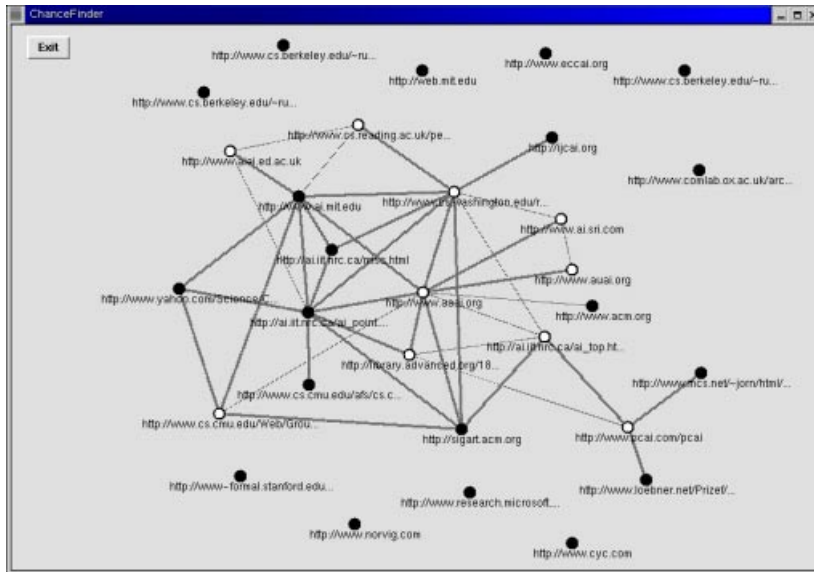


Fig. 59.4. An output for 'Artificial Intelligence'.

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60. A Document as a Small World

Yutaka Matsuo^{1,2}, Yukio Ohsawa^{2,3}, and Mitsuru Ishizuka¹

¹ University of Tokyo, Hongo 7-3-1, Bunkyo-ku, Tokyo, Japan
matsuo@miv.t.u-tokyo.ac.jp

² PRESTO, Japan Science and Technology Corporation,
Tsutsujigaoka 2-2-11, Miyagino-ku, Sendai, Miyagi, 983-0852 Japan

³ University of Tsukuba, Otsuka 3-29-1, Bunkyo-ku, Tokyo 113-0012, Japan

A document is represented by a network; the nodes represent terms, and the edges represent the co-occurrence of terms. This paper shows that the network has the characteristics of being small world, i.e., highly clustered and short path length. Based on the topology, we can extract important terms, even if they are rare, by measuring their contribution to the graph being small world.

60.1 Introduction

Graphs that occur in many biological, social and man-made systems are often neither completely regular nor completely random, but have instead a “small world” topology in which nodes are highly clustered yet the path length between them is small [60.7, 60.5]. Watts and Strogatz have shown that a social graph (the collaboration graph of actors in feature films), a biological graph (the neural network of the nematode worm *C. elegans*), and a man-made graph (the electrical power grid of the western United States) all have a small world topology [60.7, 60.6]. World Wide Web also forms a small world network [60.1].

In this paper, we first show the graph derived from a document has the small world characteristics. Then we develop a new algorithm to find important terms by measuring a term’s contribution to make the world small.

60.2 Small World

We treat an *undirected, unweighted, simple, sparse and connected* graph. (We expand to an *unconnected* graph in Section 60.4.) To formalize the notion of a small world, Watts and Strogatz define the clustering coefficient and the characteristic path length [60.7, 60.6]:

- The *characteristic path length*, L , is the path length averaged over all pairs of nodes. The path length $d(i, j)$ is the number of edges in the shortest path between nodes i and j .
- The *clustering coefficient* is a measure of the cliqueness of the local neighbourhoods. For a node with k neighbours, then at most ${}_k C_2 = k(k-1)/2$

edges can exist between them. The clustering of a node is the fraction of these allowable edges that occur. The clustering coefficient, C is the average clustering over all the nodes in the graph.

Watts and Strogatz define a small world graph as one in which $L \geq L_{rand}$ (or $L \approx L_{rand}$) and $C \gg C_{rand}$ where L_{rand} and C_{rand} are the characteristic path length and clustering coefficient of a random graph with the same number of nodes and edges. They propose several models of graphs, one of which is called β -Graphs. Starting from a regular graph, they introduce disorder into the graph by randomly rewiring each edge with probability p as shown in Fig.60.1. If $p = 0$ then the graph is completely regular and ordered. If $p = 1$ then the graph is completely random and disordered. Intermediate values of p give graphs that are neither completely regular nor completely disordered. They are small worlds.

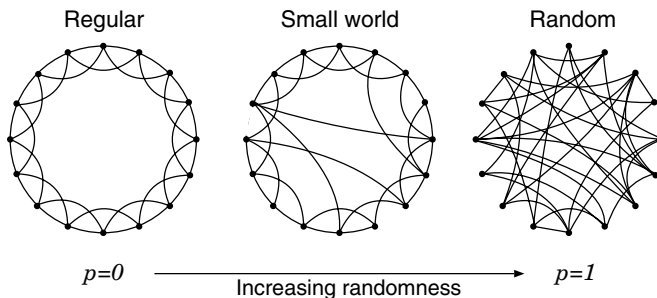


Fig. 60.1. Random rewiring of a regular ring lattice.

Walsh defines the proximity ratio $\mu = (C/L) / (C_{rand}/L_{rand})$ as the small-worldliness of the graph [60.5]. μ is larger than 1 in the graphs with a small world topology.

60.3 Term Co-occurrence Graph

A graph is constructed from a document as follows. We first preprocess the document by stemming and removing Salton's *stop words*. We apply n -gram to count phrase frequency. Then we regard the title of the document, each section title and each caption of figures and tables as a sentence, and exclude all the figures, tables, and references. We get a list of sentences, each of which consists of words (or phrases).

Then we pick up *frequent terms* which appear over a user-given threshold, f_{thre} times, and fix them as nodes. For every pair of terms, we count the *co-*

occurrence for every sentences, and add an edge if the Jaccard coefficient exceeds a threshold, J_{thre} ¹.

Table 60.1 is statistics of the small-worldliness of 57 graphs, each constructed from a technical paper that appeared at the 9th international World Wide Web conference (WWW9) [60.8]. From this result, we can conjecture these papers certainly have small world structures. However, depending on the paper, the small-worldliness varies.

Table 60.1. Statistical data on proximity ratios μ for 57 graphs of papers in WWW9.

	L	L_{rand}	C	C_{rand}	μ
Max.	4.99	3.58	0.38	0.012	22.81
Ave.	5.36	—	0.33	—	15.31
Min.	8.13	2.94	0.31	0.027	4.20

We set $f_{thre} = 3$. We restrict attention to the giant connected component of the graph, which include 89% of the nodes on average. We exclude three papers, where the giant connected component covers less than 50% of the nodes. We don't show the L_{rand} and C_{rand} for the average case, because n and k differs dependent on the target paper. On average, $n = 275$ and $k = 5.04$.

One reason why the paper has a small world structure can be considered that the author may mention some concepts step by step (making the clustering of related terms), and then try to merge the concepts and build up new ideas (making a 'shortcut' of clusters). The author will keep in mind that the new idea is steadily connected to the fundamental concepts, but not redundantly.

60.4 Finding Important Terms

Admitting that a document is a small world, how does it benefit us? We try here to estimate the importance of a term, and pick up important terms, though they are rare in the document, based on the small world structure. We consider 'important terms' as the terms which reflect the main topic, the author's idea, and the fundamental concepts of the document.

Below we show a series of definitions to measure the importance of a term.

Definition 60.4.1. An extended path length $d'(i, j)$ of node i and j is defined as follows.

$$d'(i, j) = \begin{cases} d(i, j), & \text{if } (i, j) \text{ are connected,} \\ w_{sum}, & \text{otherwise.} \end{cases} \quad (60.1)$$

¹ In this paper, we set J_{thre} so that the number of neighbors, k , is around 4.5 on average. The Jaccard coefficient is simply the number of sentences that contain both terms divided by the number of sentences that contain either terms. This idea is also used in constructing a referral network from WWW pages [60.2].

where w_{sum} is a constant, the sum of the widths of all the disconnected subgraphs. $d(i, j)$ is a path length of the shortest path between i and j in a connected graph.

Definition 60.4.2. Extended characteristic path length L' is an extended path length averaged over all pairs of nodes.

Definition 60.4.3. L'_v is an extended path length averaged over all pairs of nodes except node v . L'_{G_v} is the extended characteristic path length of the graph without node v .

Definition 60.4.4. The contribution, CB_v , of the node v to make the world small is defined as $CB_v = L'_{G_v} - L'_v$.

If node v with large CB_v is absent in the graph, the graph gets very large. In the context of documents, the topics are divided. We assume such a term help merge the structure of the document, thus important.

60.5 Example

We show the example experimented on [60.4], i.e. the longer version of this paper. Table 60.2 shows the frequent terms and Table 60.3 shows the important terms measured by CB_v . Comparing two tables, the list of important terms includes the author's idea, e.g., *important term* and *contribution*, as well as the important basic concept, e.g., *cluster* and *coefficient*, although they are rare terms. However the list of frequent terms simply show the components of the papers, and are not of interest.

Table 60.2. Frequent terms.

Term	Frequency
<i>graph</i>	39
<i>small</i>	37
<i>world</i>	37
<i>term</i>	34
<i>small world</i>	30
<i>node</i>	29
<i>paper</i>	21
<i>length</i>	21
<i>document</i>	19
<i>edge</i>	19

Table 60.3. Terms with 10 largest CB_v .

Term	CB_v	Frequency
<i>small</i>	3.05	37
<i>term</i>	2.80	34
<i>important term</i>	1.93	7
<i>contribution</i>	1.64	6
<i>node</i>	1.00	29
<i>make</i>	0.82	6
<i>cluster</i>	0.57	15
<i>graph</i>	0.54	39
<i>coefficient</i>	0.52	8
<i>average</i>	0.50	8

Lastly, Fig. 60.2 shows the graphical visualization of the world of this paper. (Only the giant connected component of the graph is shown, though other parts of the graph is also used for calculation.) We can easily point out the terms without which the world will be separated, say *small* and *important term*.

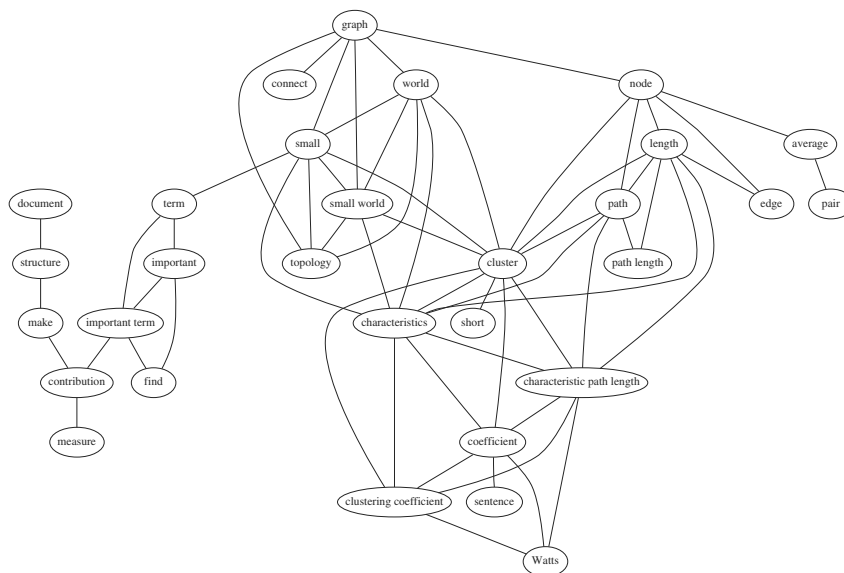


Fig. 60.2. Small world of the paper.

60.6 Conclusion

We expect our approach is effective not only to document indexing, but also to other graphical representations. To find out structurally important parts may bring us deeper understandings of the graph, new perspectives, and chances to utilize it. A change, which makes the world very small, may sometimes be very important.

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61. Support System for Creative Activity by Information Acquisition through Internet

Wataru Sunayama and Masahiko Yachida

Dept. of Systems and Human Science, Graduate School of Engineering Science, Osaka University, Toyonaka, Osaka 560-8531, Japan
sunayama@sys.es.osaka-u.ac.jp

Social activities are divided into two types. One is a creative activity by the combination of the existing object, and another is an imitative activity by which the created matters settles. Since a creation is realized by the combination of existing knowledge and information, people cannot create new things without thinking about previous works and their proper combinations. This paper proposes a framework for supporting a creative activity by combinations.

61.1 Introduction

Social activities are divided into two types. One is a creative activity by the combination of the existing object, and another is an imitative activity by which the created matters settles. As human beings have a nature of "Tire", people always seek novel things. Therefore, it can be said that the society is kept by mutually creations. Generally, since a creation is realized by the combination of existing knowledge and information, people cannot create new things without thinking about previous works and their proper combinations. The framework described in this paper supports discovery of unknown relations and combinations of information concealed in WWW database. By using this framework, one will be able to find a new theme of study or will be able to create a hot-selling product.

61.2 Framework for Creative Activity

A framework for creative activities is shown as the figure 61.1. This framework consists of User, Search System, Data Mining System and Interface for supplying knowledge. A search system in the framework needs search keywords as user's input, and outputs arranged relational keywords in a two-dimensional interface after a Data mining processes for extracting useful information. Users make his/her own interest concrete, acquire relational information and do creative activities with a discovery of unknown relationships by the repetition of a search and a supply of keywords. Relational keywords are extracted from Web pages matched with user's each search keyword. In the interface, the system supplies not only keywords but also some additional information

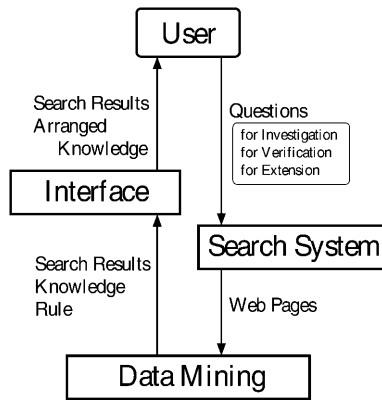


Fig. 61.1. A System for Creative Activities

such as a summary of output Web pages. In the rest of this section, each of them is defined and explained.

61.2.1 User Discovers a Viewpoint of the Combination

In the current world, the information in WWW is unknown for a user but known for the author of each Web page. Another words, a new idea comes from a combination of known ideas. A brand new combination may has a brand new viewpoint. However, this number of combination will be so enormous that a person cannot match objects by hand. Therefore, the system which provides users with keywords as chances that can be viewpoints is proposed.

As for this viewpoint, an agreement or a disagreement will be needed for two which are combined. This is realized by words that determines those two are agreement or disagreement. In short words, to discover this viewpoint is a discovery for creation. This may be a kind of discovery by co-occurrence[Langley 87]. For example, two companies will be merged by a viewpoint that a company must survive or must pursue profits. Therefore, this framework aims at constructing a new system which aids users to discover new combinations by suggestions of viewpoints representing an agreement or a disagreement. However, nothing will come without inputs of user's mind or interests. So users use Internet search systems with latent and vague disires in their mind.

61.2.2 Support System for Search Systems

Most users of the Internet want to acquire information what the users didn't know. However, the users are hard to search by proper search keywords in the domain the users don't know well. Then, a system which aids search processes by interactions between a user and the system is useful. Namely, such a system will:

1. Make a user interest concrete.
2. Aid a user to acquire relational information.
3. Aid a user to discover unknown relationships among search keywords.

In this paper, along with points 1. and 2., the point 3. is the most notable. Another words, this system aids users to develop a new goods or to find a new breakthrough of their study by inputs of user's original combination of search keywords.

Three creative purposes of using search engines, as in the figure 61.1, are investigation, verification and extension. As these keywords are already described in 61.1, Investigation and Verification aim at focusing information, and Extension aims at extending information related to a search keyword. Therefore, a support system for search engine is surely not a search engine but is a contrivance to support above purposes. The contrivance is realized by Data Mining and an interface for displaying knowledge.

61.2.3 Data Mining from Web Pages

Data Mining[Fayyad 96] is to seek useful rules and knowledge from enormous data wearhouse. Some of them are derived from association rules[Agrawal 94] and conditional probabilities defined by the co-occurrence of data. In the Data Mining module of the framework, some relational keywords of search keywords are extracted from current Web pages, and relational, summarized and some kind of useful knowledge are expected to be supplied. The features of Web database are as follows;

1. Enormous:Not all data can be in use.
2. Dynamic:The data is always changing.
3. Heterogeneous:A data includes some topics and viewpoints.

One of the methods to cope with these features is needed to construct a system. The most important point is how to restrict input data, such as pages in specific domains, pages retrieved by a keyword(including a specific keyword), its freshness and so on. Along with these, the same things are applicable to a single Web page. That is, a constructor must think how to divide and how to interpret a page to extract essences each user disires.

61.2.4 Interface for Knowledge Refinement

It is important for a user to understand relationships between search keywords and existing Web information. A two-dimensional search interface is needed to know tendencies of Web information, for making a concrete search condition and for getting an idea of a new topic. Therefore, relational keywords, as outputs of this framework, are arranged neatly in a two-dimensional search interface. Practically, though keywords are ultimate summarized information

of Web pages, those are fragments of sentences. Some users may want a summarized sentence that is chained by keywords, because a word has various meanings. Therefore, some complementary information will also be useful. The interface for interactive discovery needs some components which make up each loss occurred by the restriction of the data. Finally, this framework supplies an interface with which graphical user interface is covered.

61.3 Experimental System

Currently, though the prototype system is under construction, each module have already worked separately [Sunayama 99, Sunayama 00, Sunayama 01].

Now, the Data Mining methods to extract relational keywords is to select keywords commonly appeared in Web pages including a search keyword [Sunayama 99]. However, this is not a complete method because a word has various meanings, and because a word may not be used suitable for a user interest. A keyword in a Web page should be extracted as topical keyword of the page and of the user.

Panoramic View System [Sunayama 01] extracts topic keywords which depends on keywords user given. Therefore, these two methods for acquiring relational keywords will be combined in the new system. We'd like to have some additional information for grasping information on the Web. Panoramic View System can acquire key sentences if Web pages. As a result, users can choose information quickly and can get more information.

A two-dimensional search interface have already appeared in [Sunayama 00]. Relational keywords were arranged in two-dimensional interface, and users could make out the relationship between search keywords and relational keywords easily. In the figure 61.2, search query is "(CM OR Movie) AND Film AND Popular AND (Ryoko OR Hirose)", and relational keywords are arranged. Search keywords are clustered by common relational keywords, so two keywords "(CM OR Movie)" and "Film" are clustered in the same category. Some keywords arranging in the interface will be hard to explain why those keywords are output as relational keywords. Such keywords will be treated as unknown or new common points of search keywords. Then, the user will examine the details of the keywords why the keywords have output. In general, the keywords become a start point of examining process to find a new research topic and to find a strategy of administration.

This cycle of search and acquiring information will give birth to new ideas. This system supplies users with chances for knowing trends of the world because a user will be in the state that the user only knows unknown viewpoints of the combination.

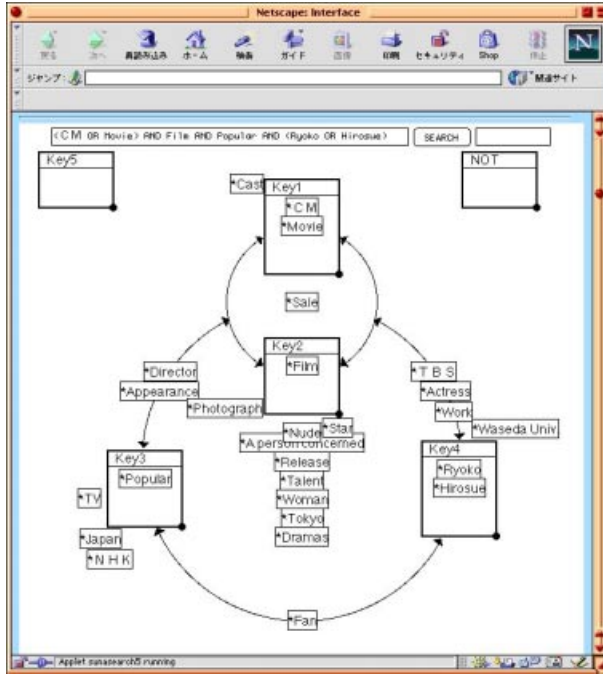


Fig. 61.2. Search Interface for Interactions

61.4 Conclusion

This paper proposed a framework for creative activities. Creative activities are necessary for our usual life and the affluent society. Especially, it is effective for people to imply new viewpoints of the combination which has never been thought out. Certain symbolic words are useful for users to concrete one's idea, and to know relational knowledge and to expand their ideas. May this new century will be a creative century!

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62. An Approach to Support Long-Term Creative Thinking and Its Feasibility

Hirohito Shibata and Koichi Hori

Department of Advanced Interdisciplinary Studies, University of Tokyo
RCAST, 4-6-1 Komaba, Meguro-ku, Tokyo 153-8904, Japan
{shibata, hori}@ai.rcast.u-tokyo.ac.jp

We propose a novel method and its implementation to support long-term idea-generation in everyday life. Our system consists of two components: a management system for problems and ideas named IdeaManager, and a personal information storage system named iBox. Considering input of information in iBox as a clue event for idea-generation, iBox searches related problems and ideas in IdeaManager and presents the result if any. Its aim is to support non-intentional idea-generation. In a long-term user study, we confirm the feasibility of our approach.

62.1 Introduction

Since the end of 1980's, a number of systems to support idea-generation, called creativity support systems, have been proposed [62.4]. However, most of them have not gained widespread use. The authors believe this is because they support isolated aspects separated from professionals' daily activities [62.2]. They only support short-term thinking in front of their systems. They assume that users use them while consciously generating ideas. However, considering our experiences and prior cases of idea-generation, it is obvious that a person needs to think for a long time. It is rarely necessary to generate ideas immediately and most problems or themes allow sufficient time to acquire satisfactory ideas. Moreover, there are more cases of sudden idea-generation at times when a person does not try to generate ideas consciously than the cases of idea-generation generated in intentional thinking [62.5].

Based on these claims, we have been pursuing a system to support long-term creative thinking in everyday life. Our everyday life is filled with stimuli. They might work as clues to generate ideas. They are chances to generate ideas. Based on the thought, "A chance is not what is given. A chance is what we should get by ourselves", we propose a system that amplifies chances to generate ideas.

To begin with, we propose our system. Its characteristic is to cooperate with a personal information storage system used in daily life. It supports activities where information management plays an important role and original ideas are needed, for example by researchers or planners. Next, we explain the results of long-term user study of the system.

62.2 System Overview

Based on the observation of actual idea-generation, we have built a system to support non-intentional idea-generation in long-term daily activities (refer to [62.5] in details). Our system consists of two components: a management system for problems and ideas named *IdeaManager* (Figure 62.1), and a personal information storage system named *iBox* (Figure 62.2). They run on Windows 95/98/NT 4.0/2000 and are implemented using the search engine of Albase¹ [62.3].

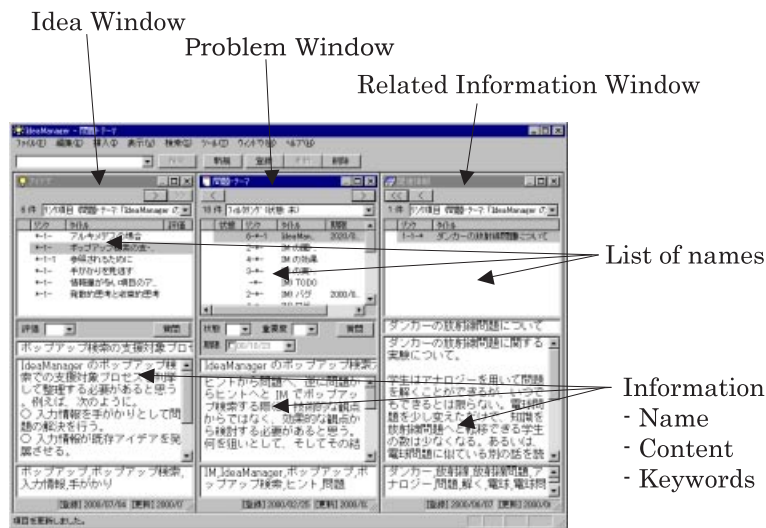


Fig. 62.1. A screen shot of IdeaManager

IdeaManager. In long-term idea-generation, a person tries to seek ideas and refine them many times until he or she acquires satisfactory ones. Here, for the next trial of idea-generation, he or she must recall the problem. In order to avoid forgetting problems and their ideas, IdeaManager supports the retention and management of them.

All information in the IdeaManager has its *name* and *keywords*. In the current version, only text can be stocked. Information stocked in IdeaManager is divided into following three types: *problems*, *ideas*, and *related information*. Information is stocked in a corresponding window. Users can view problems, ideas, and related information, side by side. Also, using link function, users can manage problems with its corresponding ideas and related information.

IdeaManager provides the following basic search functions: search by keywords, full text search, search by date, and list of all information. Also,

¹ Now, Albase became an item for sale of Fuji Xerox Co., Ltd. as Johobako 4.0.

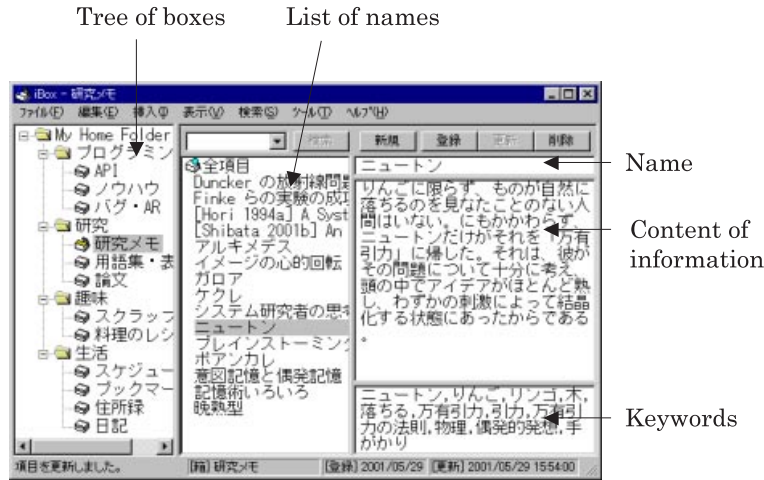


Fig. 62.2. A screen shot of iBox

users can filter information using attributes of information, for example, deadlines, importance, and so on. Each of these functions returns a list of names. Selecting a name of the list, users can see the information with its name and keywords.

iBox. iBox is a personal information storage system used in various types of situations in both work and other everyday life. Actually, in our laboratory, almost all students use iBox in their actual daily activities.

Similarly to IdeaManager, iBox stocks all text information with its *name* and *keywords*. iBox provides the same basic search functions as IdeaManager. Each of these functions returns a list of names. Selecting a name of the list, a user can see the information with its name and keywords.

Cooperation between IdeaManager and iBox. Our system provides two types of cooperation. A registration of information in one application triggers a search of information in another application and presents the results (Figure 62.3).

Information stocked in iBox reflects a users' interest. Such information may have something to do with users' current problems and work as a hint for consideration of these problems. When information is registered in iBox, iBox searches related problems and ideas of IdeaManager and pops up the results if any. We hope that users will be able to generate or enhance ideas for searched problems or ideas using registered information as a hint. Information stocked in iBox must have novelty or emergence which Finke et al. [62.1] call 'preinventive properties'. A trial of idea-generation at this timing leads to a function-follows-form approach of idea-generation described by Finke et al.

Also, when users recognize a problem, presenting related information might stimulate users' consideration. Then, when a problem or an idea is

registered in IdeaManager, IdeaManager searches related information in iBox and pops up the results if any. We hope that users will be able to generate or enhance ideas for registered problems or ideas using searched information as a hint.

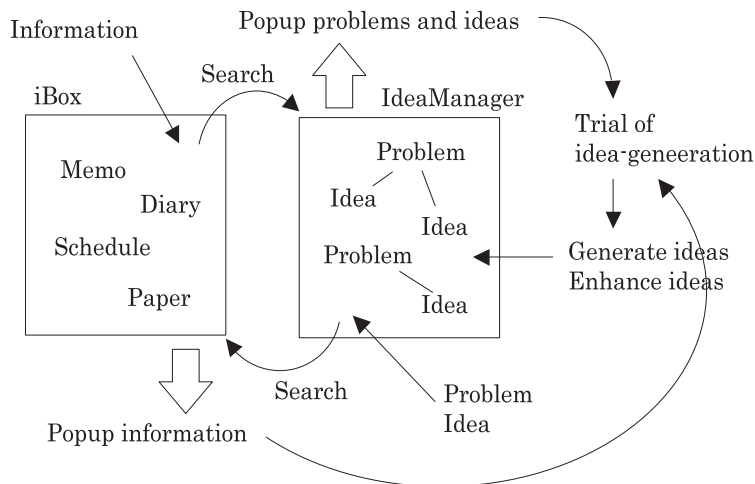


Fig. 62.3. Cooperation between IdeaManager and iBox

62.3 Long-Term User Study

We carried out a long-term user study. The users were two researchers and one of them is the author of this paper. The period of study was more than seven months (221 days). During this period, the users always had notebook PCs with them and managed problems and ideas in their actual activities. Both IdeaManager and iBox saved action logs, for example registration, search, reference of information, and so on. The action logs of one of the users were then analyzed.

62.3.1 Behavior Analysis on Pop-Up

During the experimental period, the user registered 1,242 pieces of information in iBox. During this period, iBox popped up IdeaManager 70 times and in 46 times of these pop-ups the user referred to at least one piece of information. He also registered 25 problems and 49 ideas. IdeaManager popped

up iBox more than 9 times² and in 4 of these pop-ups he referred to at least one piece of information. We analyzed his behavior during these 50 pop-ups referring to at least one piece of information. This analysis is based on retrospective verbal protocol obtained while reviewing behavior using action logs and his diary. We show some typical behavior that pop-ups effectively worked in the following.

Example 1. The following is the first example for a pop-up driven by iBox. (1) The user registered information named "Spacing effect of study" (in Japanese) in iBox. (2) Next, IdeaManager popped up and one problem and one idea were searched. (3) He referred to a problem named "How to search in a pop-up" (in Japanese) in IdeaManager. (4) He searched two ideas linked to the above problem of step 3. (5) He referred to the ideas of step 4. (6) He registered an idea named "IdeaManager has a effect of spacing effect" (in Japanese) in IdeaManager. (7) He linked the problem of step 3 to the idea of step 6.

In this procedure, the user generated an idea for a presented problem. He reported that he had realized the pop-up effectively stimulated the new idea. He also reported that he had tried to generate ideas to combine the information of iBox and the searched problem intentionally. We think that pop-ups driven by iBox could support intentional combination of information and problems.

Example 2. The following is the second example for a pop-up driven by IdeaManager. (1) The user registered an idea named "Implementation of search by ID in iBox" (in Japanese) in IdeaManager. (2) Next, iBox popped up and 9 pieces of information were searched. (3) He registered a problem named "Desired functions for search engine of Albase" (in Japanese) in IdeaManager. (4) He referred to some information on API of Albase in iBox. (5) He registered an idea named "How to use the API of search engine of Albase" (in Japanese) in IdeaManager. (6) He linked the problem of step 3 to the idea of step 5.

In this procedure, the user generated an idea referring to information presented by iBox. He reported that he had realized the idea of step 1 could adapt other APIs of Albase and his desired function could be substituted for a combination of other APIs. He also reported that the idea was a bit of an improvement and he could probably generate the same idea without the pop-up function. However, in this case, pop-up function afforded him to seek ideas then and there at the time. Without the pop-up function, he might not have tried to seek ideas for the registered problem and leave it as is. We think pop-ups driven by IdeaManager could support spontaneous thought when users recognize a problem.

² There was a bug in the log. In fact, there were more pop-ups driven by IdeaManager.

62.3.2 Effects and Open Problems

In this user study, we cannot necessarily discuss whether our system worked effectively or not. However, there were a number of indicators for long-term creativity support. We observed the following effects of our systems. 1) Users can feel relief because they can leave the management of problems and ideas to IdeaManager. 2) Pop-ups driven by iBox encourage users to think of intentional combination between a problem and information (Example 1). 3) Pop-ups driven by IdeaManager encourage users to not only register a problem but also try to think and generate ideas when they recognize a problem (Example 2).

As open problems, we observed the following design problems of our system. 1) It is often difficult to distinguish a problem from an idea. We need to modify the design of IdeaManager or to give a clear guide to distinguish a problem from an idea. 2) If there is a lot of information presented by a pop-up, users do not feel like viewing them. We need to control the amount of information in pop-ups. 3) The current pop-up algorithm of IdeaManager is a keyword matching. Sometimes, searched information has clear relativity with registered information and it does not stimulate users' thinking. We need to enhance the search mechanism.

62.4 Conclusions

We presented our long-term creativity support system cooperating with a personal information storage system. The aim of this cooperation is to enable interesting information acquired in daily life to work as a clue for idea-generation. In a long-term user study, we observed some evidence that pop-up functions worked effectively. We think that feasibility of our approach has been confirmed.

Now, we are enhancing our system based on the result of this study and planning a formally designed experiment.

Acknowledgements. Our system is implemented using the search engine of Albase implemented in Fuji Xerox Co., Ltd. Especially, we thank Yoshifumi Matsunaga for quick and warm-hearted response and Eiji Ishida for implementation and technical help of Albase. Finally, we thank Kengo Omura of Fuji Xerox Co., Ltd. for his helpful comments for this research.

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63. Chance Discovery by Creative Communicators Observed in Real Shopping Behavior

Hiroko Shoji and Koichi Hori

Department of Advanced Interdisciplinary Studies, University of Tokyo
RCAST 4-6-1 Komaba, Meguro-ku, Tokyo 153-8904, Japan
Phone: +81-3-5452-5289, Fax: +81-3-5452-5312
{hiroko, hori}@ai.rcast.u-tokyo.ac.jp

Analyzing conversation between customers and salesclerks in actual purchase activities, we have found that appropriate information given by the clerk in a timely context often caused a change in customer's focus, which then led to her decision on what to buy. This mental leap phenomenon is similar to the one often observed in creative activities such as design or concept formation. We expect that the effect provided by the creativity support systems can be expected to play a similar role in purchase consulting systems as well. The examples described in this paper can be thought as cases of chance discovery by skillful sellers as creative communicators.

63.1 Introduction

Conversation or communication is a part of information exchange functionalities of stores. When customers shop in the real world, their communication with salesclerks often inspires them to purchase or enables them to make a smooth decision. We could learn a lot from the salesclerks' communication when they handle customers based on individual salesclerk's knowledge and experience.

Pu et al. pointed out that communication is important for formation and clarification of needs in purchase activities at e-commerce sites[63.7]. Studying what communication is done in the actual purchase activities and how it influences the customers' decision-making and sales promotion may be of importance in order to obtain hints for developing e-business in the future.

Accordingly, our study collected and analyzed protocols from actual purchase activities. The result showed that providing appropriate information in a timely manner in decision-making process for shopping frequently causes customers' focus to change resulting in their final decision. Such a *mental leap* phenomenon can also be seen in creative activities such as design and concept formation. Therefore, we expect that the effect which can be obtained in creativity support systems plays a similar role in purchase consulting systems at e-commerce sites.

63.2 Collecting Protocols of Actual Purchase Activities

We gathered 16 women in 20's to 30's who could continuously cooperate as examinees in order to collect protocols in actual purchase activities. When they went shopping with no companions, we had them carry a tape-recorder to record the conversation with salesclerks in the stores.

A total of 107 protocol data were collected. However, 33 cases among them had hardly audible voices of salesclerks and could not be analyzed. As for another 23 cases, even judging together with reports, we could not determine what demonstrative words such as "this" and "that" indicate. Therefore, remaining 51 cases were analysed as protocol data.¹

63.3 Analysis and Result

63.3.1 Expected Reaction

Usually, the role played by salesclerks as advisors is primarily to help customers discover possible choices by presenting appropriate choices and to help them consider and evaluate choices by providing information. We call this kind of salesclerks' response *expected reaction* in this study.

For example, protocol sample #1 as shown below is one example of expected reactions. Here, responding to the customer's requirement that "because an item as a current choice (candidate A) is short, longer one is better", the salesclerk presented another item (candidate B) matching the requirement. This can be taken as an expected reaction, where she affirmed the customer's requirement and present more appropriate choices. Whether the customers buy the item given as "more appropriate choice (from a certain aspect)" or not depends on the evaluation of the item by them. Frequently, when another choice is presented, the decision-making process moves to the next cycle, and items will be evaluated from another aspect. In this example, the customer, who requested a "longer" item focusing on the length, was presented new choice matching her requirement, then turned her attention to the "shape." Figure 1 shows this.

Protocol sample #1: Expected reaction

[Customer]: Do you have longer one with this shape?

[Salesclerk]: Well, let me see this line... (After considering and searching for a while) this one (candidate B) could be freely adjusted to your size. This type is not hemmed from the beginning so that it can be adjusted to each customer's length. This one would have no problem at all. It is long enough even for foreign models.

[Customer]: I see. What its shape is like?

¹ All the conversation was in Japanese. The conversation shown in this paper is translated into English by the authors.

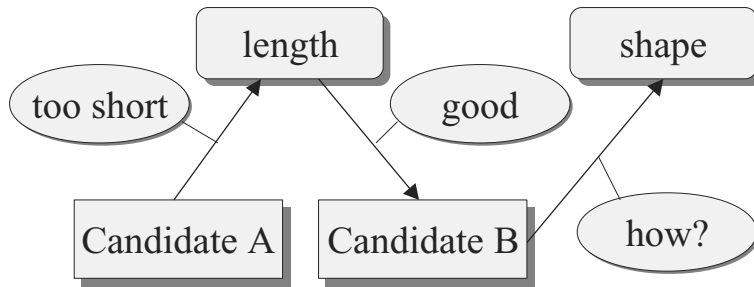


Fig. 63.1. Thinking process in the protocol sample #1

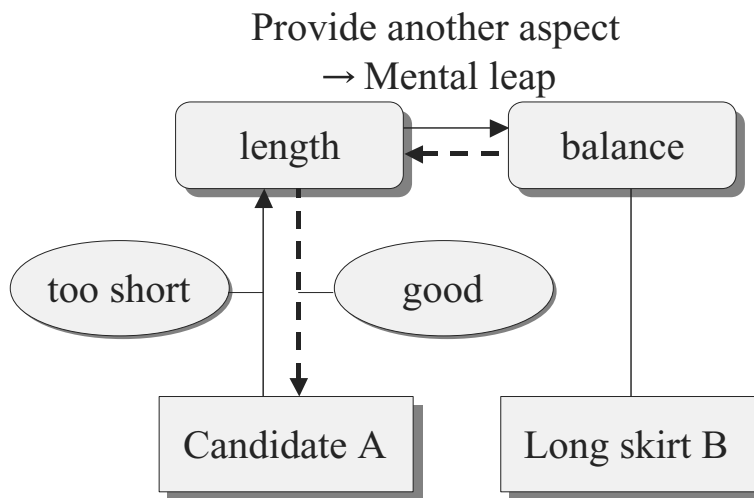


Fig. 63.2. Thinking process in the protocol sample #2

63.3.2 Unexpected Reaction

Salesclerk's reaction in actual purchase activities is not always an expected one. Affirmative reaction to what the customer says is contextually an expected advice, however, some customers actually cannot conclude only with this type of advice. In such a case, opposing customer's evaluation or mentioning *unexpected* aspects for the customer, on the contrary, may increase the chance of successful sales. The protocol sample #2 shown below is one example of such cases.

Protocol sample #2: Unexpected reaction (the case of a successful mental leap)

[Customer]: This (candidate A) is a little short.

[Salesclerk]: Such a design is popular this year. Almost every shop deals with short ones. Do you prefer longer one?

[Customer]: Too short to cover my waist...

[Salesclerk]: It depends on the balance with your skirt or pants. 'cause you're now wearing shorter tight skirt, you think that way, but if wearing a long skirt, you will feel better.

[Customer]: Really? Does it more suit to long skirt than pants?

[Salesclerk]: It depends on the shape, but tight pants would emphasize your waist. So, long skirt with an elongated shape would be better. (After searching...) For example, this type (candidate B) would best suit to your current jacket.

[Customer]: OK, can I give it (candidate B) a try?

For example, in the protocol sample #2, for the customer who was reluctant in the sense that “jacket (candidate A) is short in length,” the salesclerk provided another aspect of “the balance with lower clothes” and persuaded her to think “it’s not short” because “wearing it together with long skirt is OK.” The salesclerk recognized that the customer didn’t like the short one because “it emphasizes her body shape,” and came to the conclusion that the problem was not “clothes’ being short in length” but presenting “how to wear it not to emphasize body shape.” Figure 2 shows this.

In this way, in some cases, seemingly disagreeing with the customer conversely prompted him/her to make a decision. In the sense that opposing customer’s requirements or thoughts shown verbally, this can be taken as *unexpected reaction* by the salesclerk, which deviates from the usual flow of presenting solutions to match requirements. Furthermore, the unexpected reaction can be thought to bring the possibility of substantial change and leap in what the customer thinks. That is, an unexpected reaction by the seller in an appropriate situation may lead to a chance of the customer’s decision-making and the successful sale. In this sense, the unexpected reaction may be considered as an instance of chance discovery by the seller.

63.3.3 Successful Chance Discovery with Unexpected Reaction

Making an unexpected reaction may also increase the risk of failed conversation and unsuccessful sale because of disagreeing with the customer. However, it can conversely bring the chance to prompt the customer to make a decision. Extracting from the protocols unexpected reactions effective in decision-making by the customer, we found that two characteristic patterns of successful unexpected reactions:

1. By comparing with other items (extreme examples), broadening the customer’s range of thought and adjusting the scale of thought axes.
2. By presenting a new focus different from the one which the customer currently has, jumping her to another thought space or prompting her to make a new discovery, i.e. supporting her *mental leap*.

Interestingly, these unexpected reactions are similar to the characterization of design activities in creativity support studies[63.1][63.2]. For example, pattern 1 and 2 of unexpected reactions mentioned above can be thought as a method similar to *innovative design* and *creative design* defined by Gero[63.2], respectively. The protocol data we collected shows that presenting a new focus as shown in pattern 2, in particular, is a frequent reaction by skillful salesclerks who are good at selling goods (i.e., making a chance discovery).

In addition, our analysis showed that talking about scenes where an item is used can be effective explanation of the item's utility to help smooth mental leap. *Scene information* itself serves to enhance customer's understanding of goods and to clear their image. Actually, our protocol data collected includes many cases where scene information is frequently used. Providing scene information is expected to be useful for taking full advantage of the chance for the customer to have a mental leap for successful unexpected reaction.

The protocol the authors collected verifies that scene information is frequently used together in the situation where these unexpected reactions prompt a mental leap. For unexpected reactions by a salesclerk to cause a customer have a mental leap or jump from the current thought axes or focus, new thought axes or focus presented must be easily accepted by the customer. Unless the customer's mental leap is smoothly performed, unexpected reactions will end in failure at higher risk. Providing usage scenes in terms of scene information may be effective in promoting the customer's understanding, consequently assisting unexpected reactions to result in the success.

63.4 Discussion

This paper analyzed the conversation between the customers and salesclerks in actual purchase activities to show that the reaction by the salesclerk may promote the customer's mental leap. We found that providing appropriate information in a timely manner frequently caused the customer's thought axis or focus to change resulting in their making decision. Interestingly, such a mental leap phenomenon is similar to the one observed in creative activities like design or concept formation.

Particularly, we demonstrated in detail that unexpected reactions made to the customer's current requirements might promote her mental leap effectively. We may say that the skillful seller or *creative communicator* is the seller who can discover chances from the communication context successfully and make unexpected reactions effectively. Furthermore, we presented the cases to show that providing scene information may be useful for supporting unexpected reactions effectively. We do not assert that an unexpected reaction is always superior to an expected reaction, or leads to more successful sales. However, we may say that the skillful seller is a creative communicator.

Also, such a mental leap phenomenon can also be seen in creative activities such as design and concept formation. Therefore, we expect that a lot of the results or knowledge obtained from several studies of creativity support[63.3][63.4][63.5] can be applied to the decision-making support in purchase activities at e-commerce sites.

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64. The Role of Counterexamples in Discovery Learning Environment: Awareness of the Chance for Learning

Tomoya Horiguchi¹ and Tsukasa Hirashima²

¹ Faculty of Information Engineering, Kobe University of Mercantile Marine
5-1-1, Fukaeminami, Higashinada, Kobe 658-0022 JAPAN
Phone: +81-78-431-6263, horiguti@ti.kshosen.ac.jp

² Department of Artificial Intelligence, Kyushu Institute of Technology
680-4, Kawatsu, Iizuka, Fukuoka 820-0067 JAPAN
Phone: +81-948-29-7618, tsukasa@ai.kyutech.ac.jp

Abstract. In the context of education, a chance occurs when a learner makes a mistake. It becomes a good opportunity of learning and brings new knowledge. Novel phenomena are often given as counterexamples, that indicate the difference between a learner's prediction and the result of her/his solution. It is, however, difficult for a learner to learn from counterexamples, because if the significance of them is not clear, a learner often ignores them and learning doesn't occur. The role of a teacher (or tutoring system) is to help a learner grasp the chance. Our research focuses how to evaluate the effectiveness of counterexamples. We propose the method of doing it from two educational viewpoints: (1) Does it suggest the occurrence of error clearly? (Visibility), and (2) Does it suggest the cause of error? (Suggestiveness) Some case studies are presented to illustrate these functions. Then, we'll compare the chance discovery in other fields with ours, and discuss what is the essential for chance discovery.

Keywords: CAI, education, discovery learning environment, simulation, counterexample

64.1 Introduction

First of all, we clarify our position. Chance discovery, according to Osawa [Osawa 2000], aims at finding novel phenomena that indicate significant change in the future. It may be an good opportunity or a deadly risk according to human action. It is, however, difficult to be aware of a chance, because it often needs some kind of discontinuity of thinking. In the context of education, we can find an analogy. In learning environment, a learner tries her/his solution and often makes mistakes. The occurrence of such errors becomes a good opportunity for learning, that is, a

chance. Novel phenomena are often given as counterexamples, that indicate the difference between her/his prediction and the result. They have potential to cause a learner's conceptual change. It is, however, difficult for a learner to learn from counterexamples, because if the significance of them is not clear, a learner often ignores them and learning doesn't occur. The role of a teacher (or tutoring system) is to help a learner grasp the chance. In computer-assisted instruction, such a situation is often seen in discovery learning environment. A learner's erroneous action in computer-simulated environment yields an unexpected feedback. The task of the system is to visualize it in effective way to promote a learner's conceptual change. How to design such a mechanism is the aim of our research.

64.2 Chance Discovery in Learning Environment

In the field of computer assisted instruction, discovery learning paradigm has recently been getting important. Typically, computer simulation of restricted environment (called 'microworld') is constructed, in which a learner can directly manipulate the existing objects and see the result of her/his action intuitively. A learner explores the world and tries to discover the knowledge and laws in the learning domain. Such a situation is educationally good because it promotes a learner's initiative, motivation and interest.

Discovery learning, however, has two sources of difficulty. The one is that it needs several basic skills of 'discovery task,' e.g., how to generate a hypothesis, how to design an experiment to test it. A learner without such skills often comes to impasse or repeats objectless actions. She/he needs some assistance. One way is to provide some auxiliary tools which makes cognitive process of discovery explicit. For example, in generating hypothesis or in designing experiments, it is quite difficult to find out what are the essential elements of the domain. So, to provide a list of basic variables will be helpful. Hypothesis Editor and Monitoring Tool [Joolingen 1999] are the typical examples. Another way is to provide more 'intelligent' assistance. It gives a learner some advice concerning the contents of the discovery task, e.g., to suggest a reasonable hypothesis based on the data in hand, to judge the reasonability of the experiment to test the hypothesis. Electric Studio [Shoda 1999] is an example, of which domain is the diagnosis of electric circuit. For designing the intelligent assistance, it needs the problem solvers in discovery task. Especially, hypothesis generator and experiment designer are the essential: The former generates all reasonable hypotheses based on the data in hand, and the latter generates all reasonable experiments to test the hypotheses.

The other difficulty of discovery learning is, however, more serious. That is, too much explanation by the system deprives a learner of her/his initiative, which is the essential merit of discovery learning. (It may teach her/him what to do step by step.) It is preferable that the phenomena in learning environment themselves make a learner be aware of what to learn. Such 'educational' phenomena often appear as counterexamples, which are the phenomena a learner didn't predict. They

impresses on her/him the necessity of learning by suggesting the error in her/his action. Thus, the 'learning from mistakes' is promoted [Perkinson 2000]. Counterexamples, therefore, can become a chance.

64.3 How to Design Effective Counterexamples

A counterexample, however, must be carefully used in discovery learning. A learner often ignores the anomalous data as the error in measurement, or excludes it out of range of the hypothesis [Chinn 1993]. Even when she/he accepts the counterexample, without any help, she/he comes into impasse and cannot reach the correct hypothesis [Fukuoka 1994, Nakajima 1997]. Therefore, it is necessary to evaluate the educational effectiveness of counterexamples, to decide whether they are shown to a learner or not. (Inappropriate counterexamples confuse a learner.) In general, the followings are essential [Fukuoka 1994, Nakajima 1997] :

(1) Counterexamples must be recognized to be meaningful and acceptable. When the difference is clear and reliable between the real phenomenon and a learner's prediction, she/he easily accepts it and reconsiders her/his idea.

(2) Counterexamples must be suggestive, to lead a learner to correct understanding. They must include sufficient information for this.

We have been studying the 'counterexample-management' according to the viewpoints above. Our domain is mechanics education. Error-Based Simulation (EBS) is used, which simulates a learner's erroneous equation of motion [Hirashima 1998, Horiguchi 1998, 1999, 2000]. As a counterexample, EBS is evaluated as follows:

(1') Does objects' erroneous motion in EBS make a learner be aware of the occurrence of error? (Visibility)

(2') Does objects' erroneous motion in EBS suggest the cause of error? (Suggestiveness)

We have designed such mechanism and developed the EBS management system, of which usefulness has confirmed through some experiments. In following two chapters, we illustrate the framework for the counterexample management using EBS. Then, we'll compare the chance discovery in other fields with ours, and discuss what is the essential for chance discovery.

64.4 Designing ‘Visible’ Counterexamples

Error-Based Simulation [Hirashima 1998]

EBS is generated by mapping an erroneous equation in formula to simulation (Figure 1). It shows unnatural motion in contrast with correct one (A learner is assumed to predict correct motion). The differences arouse cognitive conflict, to promote reflection by a learner. Figure 2a shows an example. When a learner sets up Equation-B for the Block, EBS shows it ascending the Slope. The difference between EBS and correct motion is clear, so it visualizes a learner’s error well.

Clarity and Reliability [Horiguchi 1998, 1999]

In other cases, the difference isn’t always clear. In Figure 2b, for example, EBS generated from Equation-C only shows the Block moving in the correct direction along the Slope (its velocity is a little different). A learner feels difficulty in judging whether the motion is correct or incorrect. The same matter occurs for Equation-D. Changing some parameters in simulation often makes the difference clear. In the case of Equation-C, when the angle of Slope θ increases, the velocity of Block decreases, while it increases in correct motion. For Equation-D, when θ becomes zero, the Block still moves on the flat floor! Such unnatural changes in behavior also stimulates a learner, but it must be noted that ‘too large’ parameter-change spoils the reliability of simulation itself. The criteria that evaluate the clarity of EBS’s difference from correct motion (called ‘Criteria for Error-Visualization: CEV’) say the more qualitative difference of velocity and/or acceleration the EBS has, the clearer it is. The criteria that evaluate the reliability of EBS say the larger parameter-change is applied to EBS, the less reliable it becomes. We previously proposed a EBS-management mechanism using these two kinds of criteria, and confirmed its usefulness by pilot test.

The both criteria define the ‘visibility’ of EBS as a graphical presentation. The former corresponds to ‘effectiveness’ criteria and the latter ‘expressiveness’ criteria in information visualization research field [Mackinlay 1986]. The merit of this approach, in managing EBS, is that it doesn’t need the problem-solver of learning domain, and that it can transform the issue of a learner’s ability of problem-solving to the issue of her/his ability of motion perception.

Designing ‘Suggestive’ Counterexamples [Horiguchi 2000]

Error-Identification

The merit of ‘visibility’ viewpoint is its simplicity. It does not depend on the problem-solving process but only on the resulting phenomena, so it is comparatively easy to design the evaluator of counterexamples’ effectiveness. Such counterexamples, however, don’t always provide a learner useful information to correct

her/his error, and sometimes mislead her/him. This comes from the lack of consideration of the problem-solving process. Therefore, paying attention to the 'suggestiveness' viewpoint is also important.

Apparently, the problem solver which can construct the correct equation is necessary. We developed it by modelling the formulation process of equation in mechanics. The model focuses mainly on the process in which a learner enumerates the forces acting on the objects, so it consists of a set of production rules, called Force-Enumerating Rules (FERs). They describe the conditions for the forces to act. Part of them are shown in Table 1.

The correct solution inferred by the problem solver is compared with the one by a learner (inputted through the interface which allows her/him to construct equations and diagrams), and the differences are checked. Some rules are necessary which link the error-appearance on her/his solution to its cause. By considering a learner's error as the error about FERs, the rules are formulated as shown in Table 2. They are called Error-Identification Rules (EIRs), which link the erroneous part of a learner's solution to its cause and instruction strategy.

Suggestiveness

The identified cause of error must be visualized and suggested by EBS. The last set of rules we need is the one which describes what kind of motion in EBS suggests what kind of misconception in problem solving. The fundamental idea is quite simple. When a human observes an object moving, she/he feels its 'motive force' working. We apply this fact to the difference of motion. For example, assume that a learner observes a block moving to the left with deceleration when she/he predicted it moves to the left with acceleration. She/he will feel that the force which acts to the left is missing, or that the force which acts to the right is extra. The same thinking is possible about the relative motion of two objects. The rules are formulated as shown in Table 3 and 4. They are called Criteria for Cause-of-Error Visualization (CCEVs), which link the motion in EBS to the cause of error suggested.

For example, consider the problem in Figure 3. When a learner constructs the equation in Figure 3a (the direction of friction μN is erroneous), the EBS (with no parameter-change) becomes as shown in Figure 3b, in which the string shrinks. According to the CCEV in Table 4, however, this motion suggests the error about tension, which is not the cause of error in this case. Therefore, another EBS (with parameter-change) is searched as shown in Figure 3c. When the mass m_2 increases, the block's velocity increases according to the erroneous equation, while it decreases according to the correct equation. This satisfies the CCEV in Table 3, and the EBS correctly suggests the error about friction μN (Figure 3c).

64.5 Discussion

The major feature of education in chance discovery is, most people may consider, that in this field there is the Omniscient: a teacher. This view is, however, not exactly accurate. We'll explain this reason. Apparently, in other fields, one of the difficulties in chance discovery comes from unknowability: getting aware of the importance of the data that was regarded as nugacious or out of range, often brings discovery. It needs the knowledge that cannot be pre-written, so isn't intrinsically algorithmic. This is why the collaboration between human and computer is necessary. On the other hand, in education, a teacher knows 'everything' (or expected so). She/he knows what kind of error promotes a learner to learn, that is, what is the chance for a learner and when it occurs are knowable. However, how can she/he make a learner be aware of it?

Of course, to say 'This is a chance, learn!' has no effect. It is necessary to arouse 'reasonable doubt' about a learner's (wrong) knowledge, to orient her/him to correct understanding. A teacher must provide the appropriate information for this. In fact, to be aware of a chance and to make a learner be aware of it, are quite different matters. The advantage of a teacher is the rich knowledge of the learning domain. She/he can analyze it and design the appropriate instructions. Visualization, as shown some examples in this paper, will be one of promising methods.

We conclude this paper by pointing out the other important viewpoint. In this paper, we considered only elementary problems in the learning domain, and assumed the learning process of average level. When the problems become more difficult, it also becomes difficult to reason a learner's thinking process. Solution may need some kind of discontinuity of thinking, like 'insight.' In such a situation, even for a teacher, it is not apparent what kind of error promotes what kind of learner. She/he needs to discover a chance.

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65. Integrating Data Mining Techniques and Design Information Management for Failure Prevention

Yoshikiyo Kato, Takehisa Yairi, and Koichi Hori

Department of Advanced Interdisciplinary Studies, University of Tokyo
4-6-1 Komaba, Meguro-ku, Tokyo 153-8904, Japan
{yoshi,yairi,horii}@ai.rcast.u-tokyo.ac.jp

Stories of the recent failures in complex systems tell us that they could have been avoided if the right information was presented to the right person at the right time. We propose a method for fault detection of spacecrafts by mining association rules from house keeping data. We also argue that merely detecting anomalies is not enough for failure prevention. We present a framework of design information management in order to capture and use design rationale for failure prevention. We believe that the framework provides the basis for improved development process and effective anomaly handling.

65.1 Introduction

Recently, we have experienced a series of failures in complex systems in Japan as well as other parts of the world. To list a few, there were the criticality accident at nuclear fuel plant in Tokai Village in September, 1999, the failure of the launch of Japanese Space Agency's flagship H-II rocket in November, 1999, and the fatal subway crash in Tokyo in March, 2000.

Why do these accidents happen? One of the reason is that the scale and the complexity of such systems are intractable to a single person. As a result, oversights happen more often than before in design or during operation, leading to an accident. Von Braun is said to have understood the whole system of Saturn V rocket. But it is not possible for a single person to understand the whole system with the scale and complexity of current systems, like space shuttles. Therefore, we believe that computer support is needed to manage the scale and complexity in the development process.

As the scale and complexity of a system grows, the number of people needed for the development of the system increases. As a result, communication between people becomes one of the crucial aspects of the development process. Indeed, many of the recent failures can be attributed to poor communication between developers or between development and operation. Computers are already widely used for communication like e-mails, but we believe computer could do better than merely sending e-mails back and forth.

Failures, especially the catastrophic ones, do not happen suddenly. Usually, there are some signs indicating the imminent failure. This fact is depicted in the Heinrich's law: behind one catastrophic accident, there are 30 less severe

accidents, and 300 near misses. By paying attention to these events, it might be possible to find a way to avoid imminent catastrophic accidents[65.1]. But, if we were not aware of those events, we would not be able to take any measures.

In order to prevent failures, we take two approaches: 1) fault detection by data mining, and 2) managing information for failure prevention. Data mining techniques can be used to detect anomalies that otherwise will be overlooked. However, anomalies themselves do not manifest any semantics, as they are discovered solely based on statistical properties of the data. It is humans that percept the semantics of anomalies in order to make the best use of them. We propose a framework for managing design information, not only for the improved design process, but also for providing support in the operation of the system, especially in handling anomalies of the system to prevent failures.

65.2 Fault Detection of Spacecraft by Mining Association Rules of Housekeeping Data

Fault detection is one of the key issues in the development of advanced spacecrafts. Although several detection techniques including limit-sensing, simulation and expert systems have been employed for this purpose, they have often overlooked small anomalies in the housekeeping data and some of them have led to fatal damages to the overall missions.

One reason for the difficulty is that conventional fault detection methods generally require a tremendous a priori knowledge on the system behavior for each spacecraft, whereas that kind of knowledge is not always easily available. For example, a perfect dynamics model for simulation or a complete set of production rules for expert system is usually too expensive to prepare for each spacecraft. Another reason is that these methods can grasp only limited aspects of overall spacecraft system behavior. For example, limit-sensing examines only upper and lower bounds of individual sensor values, and dynamics simulation can be performed merely on several subsystems such as attitude control system.

We proposed a fault detection method for spacecrafts based on data-mining techniques [65.2]. In this method, at first, a set of association rules, which describe "qualitative" relationships among time-series sensor signals, are mined from the accumulated spacecraft housekeeping data. Then, they are applied to monitored spacecraft telemetry to detect anomalies.

Proposed method consists of the following three steps: 1) pattern clustering of time-series data, 2) extraction of association rules among patterns sampled from different time-series, 3) real-time monitoring with acquired association rules. First two steps are performed on data which is telemetered to the ground station and accumulated during the initial phase of the operation

after the launch of the spacecraft. In the last step, association rules obtained in the previous step is applied to the real-time telemetry from the spacecraft (Fig. 65.1).

As our method attempts to check the system behavior from a different point of view using a different source of knowledge, we expect that it will be able to detect some sorts of anomalies which have been usually overlooked by conventional methods. However, it is unlikely that our method will detect all kinds of system faults. In other words, it is no wonder that conventional methods such as limit-sensing or simulation approach are more suitable for detecting some classes of faults. Therefore, we are going to make more investigation on to what kind of faults our method is more effective than other approaches.

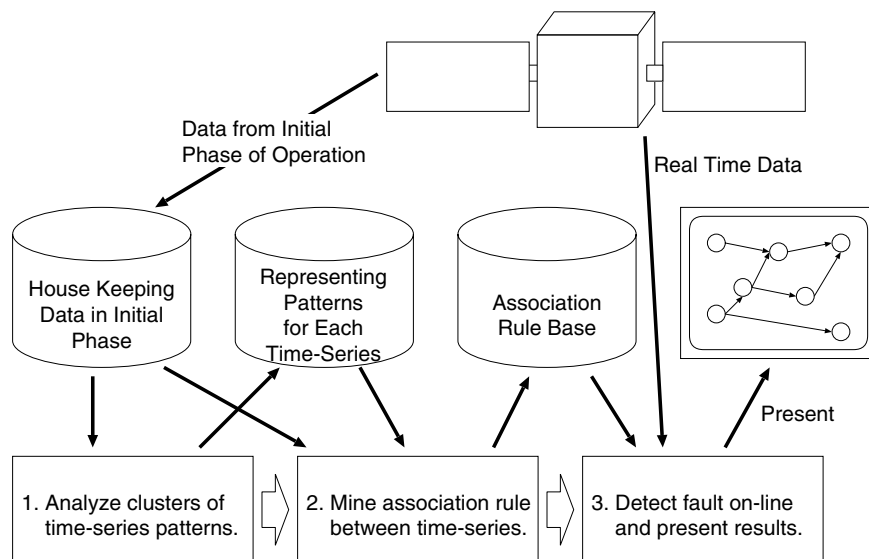


Fig. 65.1. The process of detecting anomalies of a spacecraft by mining association rules from housekeeping data.

65.3 Managing Information for Failure Prevention

65.3.1 Using Design Information for Failure Prevention

In this paper, we present an approach toward managing design information for failure prevention. We believe that certain kinds of failures can be prevented by bringing the right information at the right time to the right person.

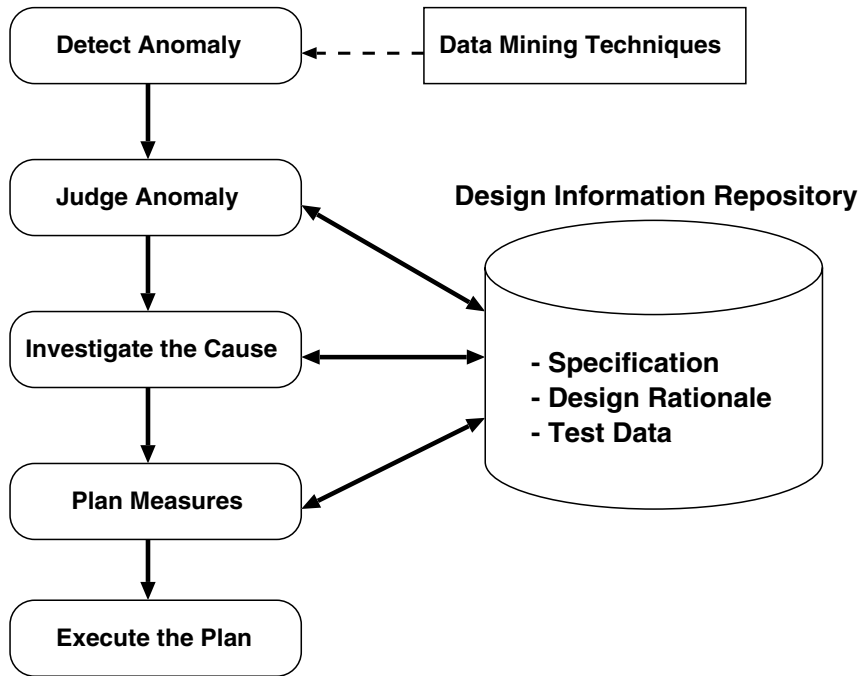


Fig. 65.2. The process of handling anomalies of a spacecraft with Design Information Repository.

The idea behind our approach is to store as much information as possible on the system by minimizing the cost to input data, while organizing the information in such a way that it can be utilized by computational power and reused later for failure prevention. In order to implement the idea, we propose a framework called *Design Information Repository (DIR)* to manage design information. The purpose of the framework is to allow every person involved in the system to access the design information and makes best use of all the information available to prevent failures.

In the process of development, manufacturing, and operation of a system, large amount of various information on the system is produced: design documents, drawings, communications between the parties involved, feedbacks from manufacturing and operation divisions, etc. Among various design information, we especially put emphasis on capturing and using *design rationale*. Design rationale is defined as the knowledge about the artifact explaining how and why it is designed the way it is. Design rationale is considered to be useful for supporting design problem-solving [65.3].

There has been much effort on capturing design rationale for a decade. Shipman et al. have depicted three perspectives of design rationale capture: argumentation, communication, and documentation [65.4]. In argumentation

perspective, what to be captured as design rationale is the designer's reasoning that occurred during the design activity. Since the argument structure is readily available, argumentation perspective benefit from various reasoning techniques. However, since human thinking itself is not structured, it takes a lot of effort to structure the argument to input into the system. This problem is known as *capture bottleneck*. In communication perspective, capture bottleneck is not present as communication between designers are recorded as it is. Though, because of the lack of structure of information, reasoning services in argumentation perspective is not available.

65.3.2 Design Information Repository

Not only design documents and drawings, but also communications between designers, arguments on design decisions, and feedbacks from manufacturers or operators can be design information. As a way to record as much information as possible and to capture design rationale, while allowing further formalization performed on the information as user demands, we propose a framework for incremental formalization and organization of information. The idea is to have all design information stored electronically, and allow access to every person involved in the target system. We call the framework *Design Information Repository*.

In this framework, all information is stored in the *repository*. Information stored in the repository can be design documents, drawings, e-mails, simulation results, anomaly reports, etc. Each information has typed attributes and query can be performed on them. Ontology can be incorporated in the system to characterize information in a suitable way for each application domain.

Around the repository, DIR provides support for project management, support for communication between developers, and reasoning service. With project management support, users, especially the project manager, will be able to manage the issues at hand. Users will be able to record issues or concerns, arguments related to those issues, and how they are resolved. A portion of a document stored in the repository can be registered as an issue, as well as an argument, or a resolution to an issue. Thus, information in the repository will be organically structured around the network of issues. Later, this structure can be used to catch unresolved issues or conflicting design decisions by reasoning engine and application specific knowledge base.

With communication support, users can register to DIR requirements or requests to other subsystems explicitly by embedding predefined tags in e-mails. DIR will check deadlines of requests and send out notices when deadline comes. All the e-mails are stored in the repository, and becomes source of information. For example, question-answer pairs can be useful information. Our vision is that, by introducing DIR, the development process will be improved by efficient handling of issues and effective communication, and it will be useful source of information in handling anomalies.

65.3.3 Handling Anomalies

Detecting anomalies itself does not prevent failures. The technique we presented in the previous section is based on statistical properties of the telemetry data, and does not give indication as to how critical the anomalies it detects are. It is human who has to decide the significance of detected anomalies.

One of the scenarios that we would like DIR to play an important role is anomaly handling. In handling anomalies, it is crucial to present “the right information at the right time.” Especially, in case of an emergency, prompt access to the needed information is crucial for dealing with the situation. The process of handling anomalies is shown in Fig. 65.2. With DIR, the operator handling an anomaly can get quick access to the relevant information. By incorporating ontology, the operator can search information by component, by behavior of the system, or by the combination of the two.

65.4 Current Work and Conclusions

This paper depicted that in order to prevent certain kinds of failures in complex systems, it is important to manage design information in such a way that the right person has the right information at the right time, as well as detecting anomalies in the system. We believe that both detecting potential failures in the system and helping human resolve presented risks by providing appropriate information are important to prevent failures of complex systems. Thus, our approach is to combine data-mining techniques and design information management. However, a lot of issues remains to be investigated on both methods before combining them.

We are now implementing the DIR framework. We plan to apply it to artificial satellite development project, and evaluate the concept in a real-life situation.

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66. Action Proposal as Discovery of Context

- An Application to Family Risk Management -

Yukio Ohsawa¹ and Yumiko Nara²

¹TOREST, Japan Science and Technology Corporation and
GSSM, Tsukuba University, 3-29-1 Otsuka, Bunkyo-ku Tokyo 112-0012, Japan

²Osaka Kyoiku University, 4-698-1 Asahigaoka, Kashiwara, Osaka 582-8582, Japan

Abstract. *A rare opinion may be more meaningful than ones supported by the majority of people. Such an opinion breaks into a popular concept if people become aware of the opinion and admire it as highly acceptable, and the prevalent support grows to be an established consensus. This paper is dedicated to aid in finding the seed of this process, i.e., an opinion with the latent popularity. The structure of the co-occurrence (occurrence in the response by the same subject) between opinions is shown to be the key to identifying such an opinion. KeyGraph, a text indexing method, is applied to an accumulated questionnaire-result data for visualizing such a structure. The experiment shows the mixture of human imagination and the output of KeyGraph, clarify the significance of opinions for forthcoming consensus.*

66.1 Introduction : Which Opinions Grow into Consensus ?

Rare information and opinions sometimes grow into a prevalent concept, if they satisfy the desire of people for information [1]. Our aim is to detect opinions the prevalence of which can satisfy a wide range of people. People first become aware of such an opinion and accept it, and the idea then may grow to be established. Along this process, the established popularity of goods such as cellular phones have grown and are prevalent today. In this paper, the problems addressed are:

- 1) *What kind of opinions grow into a consensus ?*
- 2) *How can we support human awareness on such opinions ?*

We will point out why previous analysis methods of social survey data cannot find such a growable opinion, and KeyGraph [2] is presented as an alternative method fitting our goal. From questionnaires about Kobe citizens' awareness on and the activities against risks, we show KeyGraph extracts rare but meaningful opinions. The significance growth of such obtained opinions are evaluated by interviews to a group of subjects.

66.2 KeyGraph for Noticing Consensus Seeds from Questionnaire

Opinions of people have been analyzed by several kinds of social surveys. Here, let us consider questionnaires where each question is answered in the manner of selecting one from a prepared set of opinions.

A number of methods for analyzing questionnaire results appear in the commercial software packages for data analysis. This recent phenomenon implies that existing methods, e.g. path analysis [6], co-variance analysis, multivariate analysis, clustering and several hypothesis-testing approaches are somehow authorized for social/market surveys. Several devices have also been proposed in the area of data mining for discovering comprehensible knowledge about public opinions from questionnaire data. These methods focused attention to learning frequent patterns in data, rather than detecting rare but significant opinions.

Although some data mining methods had success in explaining the conditions for the occurrence of rare events.[7], our aim is even different: A new opinion relevant to common values of two or more relevant communities, i.e. an opinion which appeared rare in the past and relevant to previous contexts of interest A_1, A_2, \dots or A_m , each being from different communities. That is, different communities having little chance to meet, can meet to make a trigger to the innovation of a new idea as mentioned in several philosophical studies [3,4] –they can discover unnoticed new ideas commonly meaningful to those different communities. As well, the awareness on the relation between one's initial value (constructed in a community) and new information (coming from another community) sometimes trigger the discovery of a new knowledge, if people involved has a proper context to share in talking or doing something together [5].

In order to identify context A_1 , it is helpful to find a set of opinions b_1, b_2, \dots and b_n made under the context of A_1 . Under A_1 , these opinions tend to co-occur, i.e., conceived by people in the same community. However, it is rare that all of $\{b_1, b_2, \dots, b_n\}$ appear in the opinion-set of the same people. It is rather usual that the set is decomposed e.g. into $\{b_1, b_2, \dots, b_x, \dots, b_y\}$ and $\{b_x, \dots, b_y, \dots, b_n\}$ appearing in the answers of people with different ideas sharing the context. A set of opinions of this kind can be extracted by connecting multiple and different set of answers to a questionnaire, each set co-occurring in the answer of the same subjects. Give such a questionnaire data, a method appropriate for extracting a set of opinions in a community taken here is to follow the two steps:

Step 1) Find co-occurring pairs, e.g., $\{b_1-b_x, b_x-b_y, b_y-b_n\}$ of answers in the data

Step 2) Connect co-occurring pairs to form the cluster of opinions under the common context, as $\{b_1-b_x-b_y-b_n\}$

The result will be a cluster as in the triangle with 84#, 202#, and 1# in Fig.1 where the term denoted as $m\#$ is an opinion in data as in Eq.(1). Some opinions may stand alone as 76#. Each of these separated opinion-set corresponds to a community of people sharing a context.

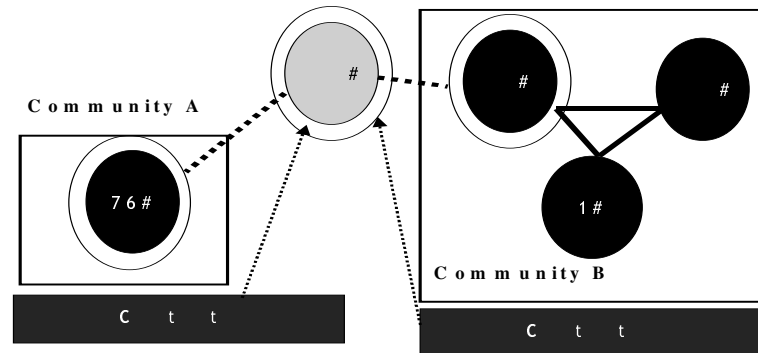


Fig. 1. Clusters of opinions in communities/contexts, and a growable new opinion 249#.

Then an opinion as 249# in Fig.1, commonly relevant to the interests of these communities, is expected to be the new topic/idea growing to be a broad consensus of society in its significance, if the opinion appears newly. KeyGraph [3] first follows steps 1) and 2) above to obtain clusters of co-occurring frequent answers in a questionnaire survey, corresponding to the contexts of existing communities. Then, it obtains answers not so frequent as ones in clusters but co-occurring with multiple clusters – the obtained answers are regarded as growable opinions to a broad social consensus related to the contexts of multiple communities. By visualizing these relations, KeyGraph induces user to be aware of significant rare opinions.

66.3 Family Perception of Risks and Opportunities

Here, we exemplify our method with the data of answers to a questionnaire about one's awareness on various risks and opportunities to survive them. The questionnaire survey was conducted by an author (Y. Nara) and CO-OP to citizens of Kobe, after the disaster of South-Hyogo earthquake (M7.0, Kobe in 1995, 6600 people victimized). The survey was of the period from Sep 10 through 30, 1998. Subjects were sampled with the random sampling method, from the Kobe Consumers Associated Society (0.6 million households). 770 valid forms were collected (50.8% valid). The questionnaire, as a whole, aimed at surveying

- (1) Citizens' interest in disaster protection activities, and their process to reach protection activities from sheer awareness on disaster risks.
- (2) The demands of citizens for the promotion of CO-OP products.

The data dealt in this paper were taken in 1998. Note here that the subjects are in a situation three years after the disaster they were directly involved in. This situation can be interpreted that they learned what occurs with a great earthquake but is forgetting some part of the feeling they had.

66.3.1. The Results of KeyGraph

An example output of KeyGraph is in Fig.2, the output of KeyGraph for the data including answers to all questions from all subjects. Hereafter, and black (dense-colored) nodes and black (solid) links form pre-existing communities i.e., clusters, and red (thin) links and red (arrowed) nodes show the links among clusters and new and meaningful opinions. Some red links are between black nodes instead of between red and black nodes. This is because a node's co-occurrence with its belonging cluster is counted but not shown by red links, for the co-occurrence is already depicted by black links in the belonging cluster.

The large cluster in the center is made of seemingly old peoples' family culture or the feeling of people caring much about their families, in Japan, e.g., 31-a-4 "we visit neighbors on moving to a new residence" "I am caring about the health of my family members" etc. On the other hand, the single-node cluster 14-d-3 in the left hand side of the figure is an answer saying "my family often talk about what do to if the next quake-disaster comes." The red node 29-5-1 standing on these two clusters means "I like the home-delivery system of CO-OP." In the discussion between ones knowing the background situations of the subjects, we interpreted this figure that people like CO-OP home delivery if they have babies or old people in bed, because they can hardly go shopping (note: Japan has no social system of baby-sitters).

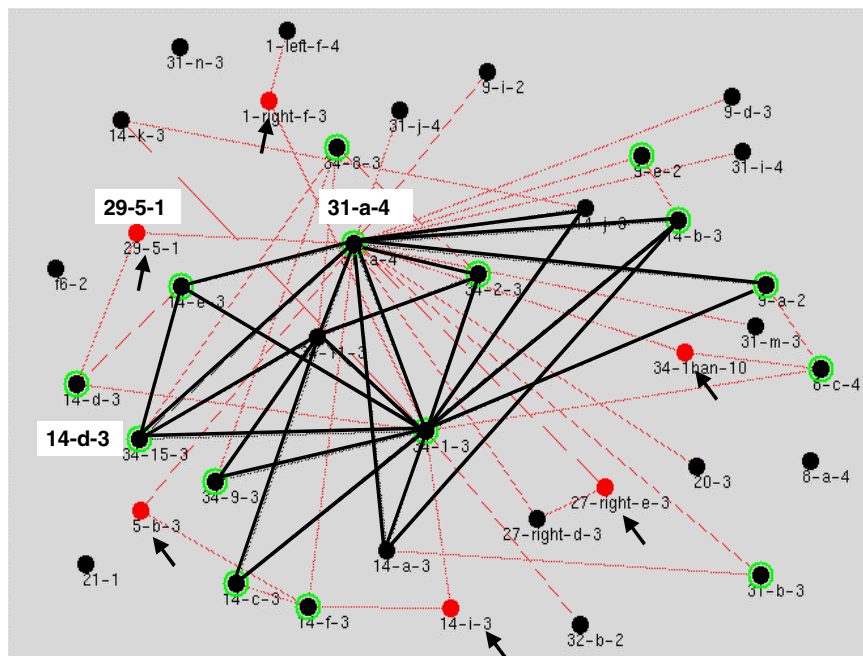


Fig. 2. The KeyGraph output for all the questions.

66.3.2 Which Opinions Grew into Consensus ?

A group interview took place with 7 university students being together in a discussion room. They looked at each figure as shown in the examples above. We had 12 red nodes in the presented five figures, and two of the figures had no red nodes. The results can be summarized: For seven of the red nodes, the students did not make confirmed comments in the beginning. Then, in the discussion they agreed to an interpretation for each red node. For each cluster of black nodes, the students agreed to one interpretation what kind of people (i.e. interest-context) the community corresponds to.

After the interview, the students and the second author (Y.Ohsawa) talked about the results without looking at the figures. At this point, all the comments were concentrated on the red nodes, not on black nodes. The reader might think the color (red) made the nodes outstanding, but the students first made comments about the black nodes. As a result, the red nodes corresponding to “new growable opinions” grew from minor into major. Furthermore, creative ideas for the management of CO-OP came out, e.g., customers buying adult- or baby-incontinents are good targets for home-delivery service, from Fig.2.

66.4 Conclusions

The model of the growth process of a minor opinion to be a consensus to the majority of people is given, and the algorithm of KeyGraph is shown to correspond to the model. KeyGraph was applied to questionnaire data about peoples’ family-wise awareness on various risks. The visual output was validated to aid in the growth of meritorious knowledge.

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67. Retrieval of Similar Time-Series Patterns for Chance Discovery

Takuichi Nishimura and Ryuichi Oka

Real World Computing Partnership

67.1 Introduction

While various techniques for chance (or risk) discovery have been proposed so far, they mainly analyze symbolized time-series data such as text or monthly sales amounts. On the other hand, we can easily access to unlabeled digitized data such as audio or video signal owing to the recent development of networks, computers and video devices. In this paper, we focus on pattern retrieval methods, which enable us to discover chances directly from such raw data.

The basic idea is that we get certain kind of features from each frame and find similar intervals in the feature sequence. Those similar intervals can be handled as symbols and various relationships among symbols can be extracted. In this paper, we call a database an input and a query a reference, because of the history of recognition method. [67.1] For some method, a feature sequence is transformed into a vector quantized (VQ) sequence.

Let us classify time-series retrieval methods into three categories as follows: (1) Retrieval of exactly same intervals, (2) retrieval of temporally warped similar intervals, (3) retrieval of intervals whose order of sub-intervals is similar. [67.7] The first methods are proposed for text retrieval.[67.1]

We propose the use of the second and third methods for chance discovery because they are applicable to audio or video signals, which usually have noises. The second methods include Hidden Markov Model (HMM) or Continuous Dynamic Programming (CDP) [67.3][67.4] which constrain the order of frames allowing temporal warp. Those methods can handle time-series data with small kind of VQs with temporal warp such as voice retrieval (in this case, VQs are phonemes). The third methods divide the query into sub-intervals and neglect the order of frames in each sub-interval while the order of sub-intervals should be similar to the query. The main application field of those methods is motion images or audio signals, which have huge kind of VQs compared to the frame number contained in the sub-interval. The similarity of such query and database is small in most of the database. Time-Series Active Search (TAS) [67.2] is the only efficient method in this method. TAS skips more and more frames as the similarity decreases and achieves quick search without degrading the retrieval rate.

TAS compares the histograms of each VQs in each sub-intervals and calculate the similarity. The method has been applied to the detection of commercials in TV programs.

On the other hand, Reference Interval-free Continuous DP(RIFCDP) [67.5] has been proposed in order to retrieve similar intervals among two time-series data. This method achieved retrieving similar voice directly from example database. [67.6] RIFCDP belongs to the second method, which finds temporally warped similar intervals.

However, no method has been proposed for the third retrieval method. If such a method is realized, We can retrieve repeated programs stored in a huge (ex. Three months) TV broadcasted database and search a crucial scene replayed in a sports program. Furthermore such a retrieval method is also effective for compression, summarization and analysis of the database.

Therefore, we propose Reference Interval-free Time-Series Active Search (RIFAS), which enables quick retrieval of similar intervals hidden in audio or video signals. [67.7] The basic idea is similar to the conventional TAS, but the skip direction is not only the input axis but also the reference axis. By the way, the TAS also achieves the function similar to RIFAS by repeating TAS shifting the interval on the reference, we hereafter call this method TAS repetition.

In this paper, RIFAS is proposed in section 2. Some approximation methods of RIFAS are proposed in section 3. Section 4 evaluates RFIAS using artificial data and motion images, concluding in section 5.

67.2 Reference Interval-Free Active Search

RIFAS is more efficient than TAS repetition because it also skips in reference axis. Here we define the similarity $S(t, \tau)$ between an interval τ to $\tau + N_d - 1$ frames in the reference and an interval t to $t + N_d - 1$ frames in the input. Then the skip width $w(t, \tau)$ is also calculated same as the active search.

We explain one example of RIFAS which is realized in this paper using Figure 67.1. Firstly, TAS is applied to the first interval of N_d frames in the reference. Hereafter we call this N_d frame as search width. Secondly, a triangle area with the height $w(t, \tau)$ is made at each matching point. Those areas are called skip area. Thirdly, as for the next interval of 2 to $N_d + 1$ frames in the reference, TAS is applied only to the points outside of all the skip areas. Example shown in figure 67.1 has only two matching points. Furthermore matching continues from low valleys of triangles to high ones as shown in the bottom in figure 67.1.

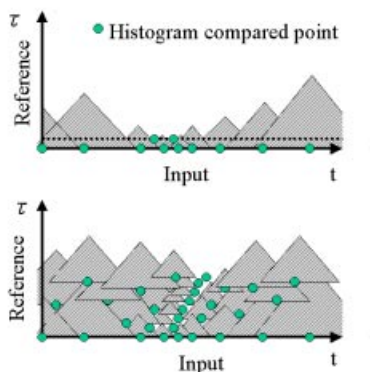


Fig. 67.1. Reference Interval-free Active Search

67.3 Experiments

In this section, we evaluate RIFAS and TAS repetition using image sequence captured from TV programs. A personal computer with OS: windows2000, CPU: K6 400MHz is used for this experiments. We used seven hours black and white image sequence (752399 frames), which were captured every 30 frames per second from TV programs. The data was converted into VQ (number from 0 to $L = 3D2^{22} - 1$) sequence. Firstly, average value of the whole image is quantized into $16(2^4)$ level. Secondly, the image is divided into three by three and the average value of each are calculated. Lastly each average value divided max average value is quantized into $4(2^{2-9})$ level. The reference and input is put same and searched similar intervals inside the image sequence data. Therefore the search area is restricted to the right bottom triangle area on (t, τ) plane.

We examined this data and made a list of similar intervals. Search width was fixed to $N_d = 3D450$ (corresponding 15 sec.). Then the ground truth list was made by selecting the true intervals more than $450 \times \theta$ frames. Threshold is changed as $\theta = 3D0.9, 0.8, \dots, 0.3$ and entropy threshold $\theta_e = 3D0, 0.05, 0, 1, \dots, 0.95$ for RIFASskip($a = 3D1$) The comaprison between RIFAS and TAS repetition is done as the maximum detection rate parameters.

The detection rate is calculated by averaging precision rate N_C/N_D and recall rate N_C/N_T . Here, N_C, N_D, N_T are the number of corrected intervals, detected intervals and ground truth intervals. The condition of correctness is the Interval detection rate is more than 0.3. This means the shift frame number is less than 50% of the interval length.

The results of RIFASskip is shown in figure 67.2. Vertical axis is threshold *theta*. At each *theta*, entropy threshold θ_e was changed and the maximum

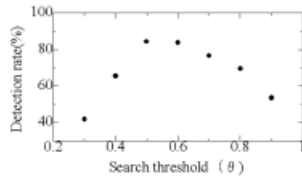


Fig. 67.2. Detection rate of RIFASskip(7 hours motion image data).

Table 67.1. Experimental results of three methods by motion image data.

	TASrep.	RIFAS	RIFASskip
Detection rates(%)	83.1	82.8	84.4
Search time(min.)	384	53	12

rate was plotted. Detection rate was highest (84.4%) at $\theta = 3D0.5$. The VQ difference in dynamic scenes is one of the reasons of the decrease of this θ compared to the artificial experiments. The VQ is also different from human sense causing detection rate decrease.

The results of the three methods, TAS repetition RIFAS and RIFASskip at $\theta = 3D0.5$ are shown in table 67.1. The results shows RIFASskip reduced computational time about 1/30 of TAS repetition and about 1/4 of RIFAS without any decrease of detection rate.

67.4 Summary

The application area of chance discovery must be enlarged by the proposal of using RIFCDP or RIFAS for video or audio signals. The future work is to introduce more efficient method than piling the area with triangle, instead rectangle. The feature extraction method is also challenging. More and more sophisticated methods are expected. The two dimensional RIFAS for image retrieval is also necessary.

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68. Fuzzy Knowledge Based Systems and Chance Discovery

Vicenç Torra

Institut d'Investigació en Intel·ligència Artificial - CSIC
Campus UAB s/n, E-08193 Bellaterra (Catalunya, Spain)
vtorra@iia.csic.es, <http://www.iia.csic.es/~vtorra>

This chapter describes fuzzy knowledge based systems and intelligent control on the light of chance discovery. It also gives some hints on the application of chance discovery from this perspective.

Keywords: Chance discovery, fuzzy knowledge based systems, control systems, level-two control systems

68.1 Introduction

One of the most successful applications of fuzzy logic are rule based systems. These fuzzy Knowledge Based Systems are nowadays commonly applied to control and modeling applications. In the typical application, Fuzzy Knowledge Based Systems are defined by means of a set of flat rules (with fuzzy predicates in the antecedents and the consequents) that are all applied at the same time. This kind of systems presents some difficulties when used to control or model complex systems. Unpredicted changes in the environment and the usually large set of variables are the most noticeable difficulties that these systems have to face. Intelligent control and hierarchical systems are two of the approaches used for controlling and modeling complex systems.

Recently, Chance Discovery was introduced as a new research field that focus on some of the issues that are difficult to deal in Data Mining. In particular, chance discovery aims to provide means to detect and take profit of new situations [68.6].

Chance discovery is described in [68.7] as *anticipation*, and quoting [68.1] the latter is: “inventing or creating new alternatives where none existed before”. Chance discovery, from the perspective of a Fuzzy Knowledge Based System designer, can correspond to the determination of the right moment for making a radical change in the system so that its performance increases. According to this, we can foresee its application on selecting a new rule base when the initial conditions of a system have changed.

In this chapter we elaborate on the application of Chance Discovery to Fuzzy Knowledge Based Systems. In Section 68.2, we describe the difficulties of developing Fuzzy Knowledge Based Systems for complex domains and some of the approaches considered in the literature to solve them. Then, in

Section 68.3, we give a general architecture for level two intelligent control and point out some relations with Chance Discovery. The chapter finishes in Section 68.4 with some conclusions.

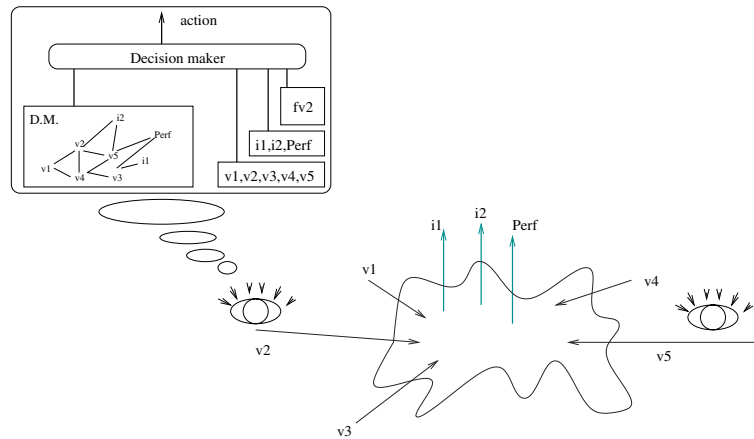


Fig. 68.1. Architecture of the system

68.2 Fuzzy Knowledge Based Systems

Fuzzy Knowledge Based Systems are one of the most successful applications of fuzzy logic and fuzzy sets technology. These systems are usually defined in terms of fuzzy rules (rules in which fuzzy terms are used in their antecedent and consequent part). Typical applications are control and modeling. See, for example, [68.3], [68.5] for details.

When the application domain moves from simple systems to complex ones, the usual operation procedure becomes infeasible. Note that typical simple applications are defined using a flat set of rules. In this case, all rules are applied at once and the final output is computed by means of a defuzzification of the combination of the conclusions of a set of rules.

In complex systems, two main difficulties arise. They relate to the number of variables of the system and on the application domain:

1. The number of variables is usually large and this causes that the number of required rules increases exponentially. This is so because typically the number of rules is m^n where n is the number of variables and m is the average number of terms for each variable. This problem is the so-called curse of dimensionality.
2. The typical environment is usually a changing one. Moreover, these changes can not be modeled in an easy way using variables. In this case, the

performance of a system can decline as soon as the properties of the environment move away from the foreseen ones.

Techniques have been developed to deal with these difficulties.

1. To deal with the curse of dimensionality, hierarchical fuzzy systems have been developed (see [68.10], [68.9], [68.8] for details). These systems replace a large rule base by a set of smaller and modular rule bases. These smaller rule bases are connected by means of additional variables and inference is chained among modules of rules.
2. To deal with the changing environment, adaptive intelligent control have been developed (see e.g. [68.4]). These systems are able to adapt the rules when the environment changes.

Karr [68.4] considers four distinct levels of intelligent control based on the adaptability of the system to the environment. These levels are the following ones:

Level-zero intelligent control system: Corresponds to a system that can improve its tracking error. This is, given a desired value for a system variable, the system is capable of reducing the difference between the actual value and the desired one.

Level-one intelligent control system: Corresponds to a system that besides of controlling the tracking error is capable of making self-improvements to the coefficients used in the control system. Some of the mechanisms for achieving this type of control are neural networks and fuzzy systems.

Level-two intelligent control system: An internally-generated performance measure is used, and optimized, at the same time the tracking error is driven to zero.

Level-three intelligent control system: Corresponds to a system that includes a planning function. They have the ability to plan ahead for certain situations, and can also autonomously simulate and model uncertainties that might appear in the system being controlled.

As an example, we can consider the well-known inverted pendulum. A change on the conditions of the pendulum - e.g. change of its mass - can invalidate the rules (this example is considered in [68.4]). In this case, a level-two intelligent control has to detect *as soon as possible* from the available variables (via some indicators) that the system has changed and update all the rules accordingly. In Section 68.3 we give an architecture to model this type of processes.

68.3 System Architecture

In this section we describe a system architecture for level-two intelligent control on the light of Chance Discovery. To do so, we consider that a certain

environment can be modeled using a set of variables and inspected through the values of this set together with the values of a set of indicators. It is assumed that the variables and the indicators define the state of the environment. *Performance* is considered a special indicator that gives a general overview of the system and that can be computed as a function of the other indicators (and the variables). Under these assumptions, the goal of the control system is to have a good (*optimum*) performance. On the light of chance discovery, we consider a *chance* as a period in which a radical modification of the Knowledge Based System¹ can have a large and positive performance.

Our approach to detect chances consists on a real-time monitoring of the variables of the application domain. This detection requires some knowledge:

1. Information on the domain. This is, domain knowledge. This domain knowledge describes all the relevant aspects related to the variables and the indicators. This is, how the variables are related one with another, and how they influence the indicators. This is to compute the indicators from the variables.
2. Information on the actions the system can perform to influence a particular variable in the environment. This is, a description of the capabilities of the system so that only relevant chances (the ones that can be of use) are detected.

It is clear that the more accurate the model is, the most chances can be discovered by the system. The need of domain knowledge and that of the actions and their outcome makes this architecture analogous to the one in model based systems [68.2]. There, instead of modeling actions, possible failures are modeled.

According to this, a Fuzzy Knowledge Based System with a chance discovery model would follow the architecture given in Figure 68.1. Several monitoring elements, or agents, monitor the variables in such a way that at each time period it is checked whether an alteration of the variable value can cause an increase of the performance. Each monitoring element would use the domain model (DM) to compute the values of the indicators ($i1, i2$) and the performance ($Perf$) from the variables ($v1, v2, v3, v4, v5$). Using this information and the model of the behavior of the variable in relation to the available actions for the system ($fv2$), the monitoring element would decide if at the present time there is a chance for improving the performance. If it is so, the adequate action will be applied.

68.4 Conclusions

In this work we have reviewed fuzzy knowledge based systems for complex systems. We have described an architecture for level-two fuzzy systems that

¹ We consider here only radical modifications of the Knowledge Based System (e.g. addition or suppression of rules) and not only minor changes

needs intensive domain knowledge to detect *chances* for improving the performance of the system. On the one hand, the need to detect the chances makes this application suitable for Chance Discovery. On the other hand, the need for intensive domain knowledge (knowledge that relates state variables and indicators and that points out which and when actions have to be undertaken) relate this approach with model based reasoning [68.2]. Further work is needed to study the suitability of the approach presented here and its adequacy in level-two fuzzy control. Also, from the point of view of chance discovery, further work is needed to clearly indentify the differences and coincidences with other artificial intelligence techniques as model based reasoning.

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69. JSAI KDD Challenge 2001: JKDD01

Program Chair: Takashi Washio

Institute of Scientific and Industrial Research, Osaka University,
8-1, Mihogaoka, Ibarakishi, Osaka, 567-0047, JAPAN

Research on knowledge discovery has attracted many people in recent years, and there is no doubt about its importance. Many benchmark data sets have been provided to the recent discovery challenge meetings in KDD, PKDD, PAKDD and JSAI conferences. Many researchers have tackled these data sets and shown their results. These efforts have indicated high potential of various knowledge discovery approaches. However, the diversity of the approaches and the data sets is so large that the significance of their resultant knowledge has not been extensively evaluated by the close collaborations among the data analysts and the domain experts.

The aim of this workshop was to tackle a set of data with the close collaborations among many analysts and an expert in the data domain and to evaluate the possibility of discovering significant knowledge in such an integrated knowledge discovery process. This data set for the challenge was provided by a medical doctor, Prof. Shusaku Tsumoto (Shimane Medical University), who is the domain expert on the meningoencephalitis diagnosis and on the supervisory board of this workshop. The data set was obtained from the meningoencephalitis diagnosis activity in a hospital. This data set has been selected by considering the availability of the collaborative domain experts and the applicability of the various approaches to the data.

This workshop strongly encouraged that the participants perform the following tasks under the collaborations with the domain expert.

1. Presentation of discovery approaches by analyst participants
2. Presentation of preliminary results by analyst participants
3. Presentation of evaluation and comments on the preliminary results by domain experts
4. Presentation of the final results by analyst participants in the workshop meeting while accounting the above evaluation and comments given by the domain expert.
5. Presentation of the final evaluation and comments by domain experts in the workshop meeting

The steps from 1 to 3 were conducted by the direct and/or electronic discussions before the workshop meeting. The steps 2 and 3 were repeated if further analyses are required. In step 5, the evaluation was made in terms of the significance of the discovered knowledge in the data domain.

I believe that this kind of KDD challenge closely collaborated among participants and a domain expert had never been planned. Also, I believe that all participants had stimulative and fruitful experiences and discussions, and had a pleasant stay at JKDD01.

70. Knowledge Discovery Support from a Meningoencephalitis Dataset Using an Automatic Composition Tool for Inductive Applications

Hiromitsu Hatazawa¹, Hidenao Abe¹, Mao Komori¹,
Yoshiaki Tachibana², and Takahira Yamaguchi¹

¹ Schoole of Information, Shizuoka University
3-5-1 Johoku Hamamatsu Shizuoka, 432-8011, JAPAN
yamaguti@cs.inf.shizuoka.ac.jp

² Schoole of Law and Literature, Ehime University, JAPAN

Here is presented CAMLET that is a platform for automatic composition of inductive applications using ontologies that specify inductive learning methods. CAMLET constructs inductive applications using process and object ontologies. We have applied CAMLET to a meningoencephalitis dataset and evaluated CAMLET. The experimental results have shown us that it supports a human expert in discovering knowledge interesting to him.

70.1 Introduction

During the last twenty years, many inductive learning systems, such as ID3 [70.3], Classifier Systems [70.1] and data mining systems, have been developed, exploiting many inductive learning algorithms. As a result, end-users of inductive applications are faced with a major problem: model selection, i.e., selecting the best model to a given data set. Conventionally, this problem is resolved by trial-and-error or heuristics such as selection-table for ML algorithms. This solution sometimes takes much time. So automatic and systematic guidance for constructing inductive applications is really required.

From the above background, it is the time to decompose inductive learning algorithms and organize inductive learning methods (ILMs) for reconstructing inductive learning systems. Given such ILMs, we may construct a new inductive application that works well to a given data set by re-interconnecting ILMs. The issue is to meta-learn an inductive application that works well on a given data set. Thus this paper focuses on specifying ILMs into an ontology for learning processes (called a process ontology here) and also an object ontology for objects manipulated by learning processes. After constructing these two ontologies, we design a computer aided machine (inductive) learning environment called CAMLET and evaluates the competence of CAMLET using several case studies from the database on meningoencephalitis with human expert's evaluation.

70.2 Ontologies for Inductive Learning

Considerable time and efforts have been devoted to analyzing the following popular inductive learning systems: Version Space [70.2], AQ15, ID3 [70.3], C4.5 [70.4], Classifier Systems [70.1], Back Propagation Neural Networks, Bagged C4.5 and Boosted C4.5 [70.5]. The analysis results first came up with just unstructured documents to articulate which inductive learning processes are in the above popular inductive learning systems. Sometimes it was a hard issue to decide a proper grain size of inductive learning processes. In this analysis, we did it under the condition of that the inputs and outputs of inductive learning processes are data sets or rule sets. When just a datum or rule is input or output of processes, they were too fine to be processes. An ontology is an explicit specification of a conceptualization. Here in this paper, a process ontology is an explicit specification of a conceptualization about inductive learning processes and an object ontology is about objects manipulated by them. In structuring many inductive learning processes into a process ontology, we got the following sub-groups in which similar inductive learning processes come together at the above-mentioned grain size: “generating training and validation sets”, “generating a rule set”, “estimate data and rule sets”, “modifying a training data set” and “modifying a rule set”, with the top-level control structure as shown in Figure 70.1.

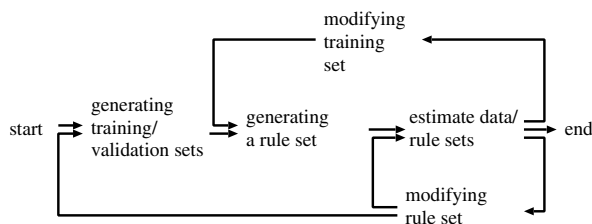


Fig. 70.1. Top-level Control Structure

In order to specify the conceptual hierarchy of a process ontology, it is important to identify how to branch down processes. Because the upper part is related with general processes and the lower part with specific processes, it is necessary to set up different ways to branch the hierarchy down, depending on the levels of hierarchy.

In specifying the lower part of the hierarchy, the above abstract component has been divided down using characteristics specific to each. For example “generating a rule set” has been divided into “(generating a rule set) dependent on training sets” and “(generating a rule set) independent of training sets” from the point of the dependency on training sets. Thus we have constructed the conceptual hierarchy of the process ontology, as shown in Figure 70.2. In Figure 70.2, leaf nodes correspond to the library of executable program codes that have been written in C, where “a void validation set” denotes

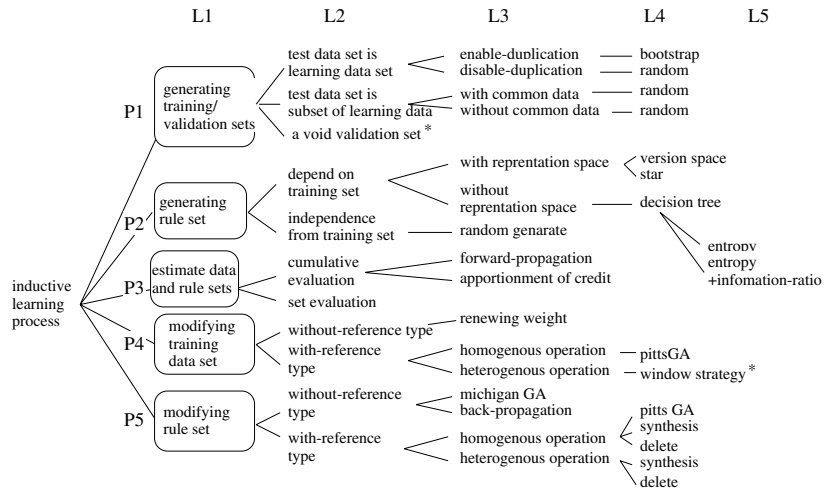


Fig. 70.2. Hierarchy of Process Ontology

that it does not distribute learning set into training/validation sets and that a learning system uses training set instead of validation set when it estimate a rule set at the learning stage. “window strategy” denotes that it refines a training set using extra-validation set which is out of character with existing rules.

70.3 Basic Design of CAMLET

Figure 70.3 shows the basic activities for knowledge systems construction using problem solving methods (PSMs) [70.6]. In this section, we apply the basic activities to constructing inductive applications using process and object ontologies.

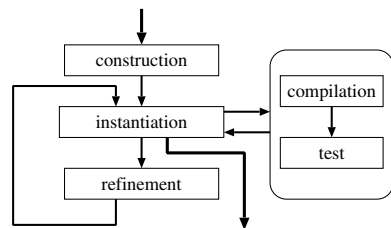


Fig. 70.3. Basic Activities

The construction activity constructs an initial specification for an inductive application. CAMLET selects a top-level control structure for an inductive learning system by selecting any path from “start” to “end” in Fi-

figure 70.1. Afterwards CAMLET retrieves the leaf-level processes subsumed in the selected top-level processes, checking the interconnection from the roles of pre-process and post-process from the selected leaf-level processes. Thus CAMLET constructs an initial specification for an inductive application, described by leaf-level processes in process ontology.

The instantiation activity fills in input and output roles of leaf-level processes from the initial specification, using data types from a given data set. The values of other roles, such as reference, pre-process and post-process, have not been instantiated but come directly from process schemes. Thus an instantiated specification comes up. Additionally, the leaf-level processes have been filled in the process-list roles of the objects identified by the data types.

The compilation activity transforms the instantiated specification into executable codes using a library for ILMs. When the process is connected to another process at implementation details, the specification for I/O data types must be unified. To do so, this activity has such a data conversion facility that converts a decision tree into classifier.

The test activity tests if the executable codes for the instantiated specification performs well, checking the requirement (accuracy) from the user. The estimation will come up to do a refinement activity efficiently.

Figure 70.4 summarizes the above-mentioned activities. A user gives a learning set and a goal of accuracy to CAMLET. CAMLET constructs the specification for an inductive application, using process and object ontologies. When the specification does not go well, it is refined into another one with better performance by crossover of control structures, random generation and replacement of system components. To be more specific, in the case of a system's performance being higher than $\delta (= 0.7 * \text{goal accuracy})$, CAMLET executes the replacement of system components. If not so, in the case of that system population size is equal or larger than some threshold ($N \geq \tau = 4$), CAMLET executes crossover of control structures, otherwise, executes random generation. All the system refined by three strategies get into a system population. As a result, CAMLET may (or may not) generate an inductive application that satisfies the user's target accuracy. When it performs well, the inductive application can learn a set of rules that work well to the given learning set.

70.4 A Case Study of Knowledge Discovery Support Using a Meningoencephalitis Dataset

We apply CAMLET to a meningoencephalitis dataset in order to evaluate how much CAMLET supports a human expert in discovering interesting knowledge. The dataset consists of 140 cases and all the cases are described by 38 attributes, including present and past history, laboratory examinations, final diagnosis, therapy, clinical courses and final status after the therapy. The

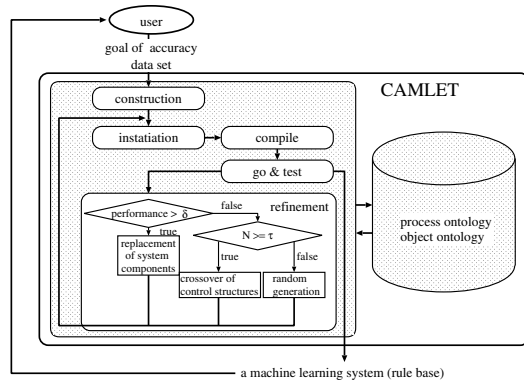


Fig. 70.4. An Overview of CAMLET

important issues for analyzing this dataset comes as follows: to find factors important for diagnosis (DIAG and Diag2), ones for detection of bacteria or virus (CULT_FIND and CULTURE) and ones for predicting prognosis (C_COURSE and COURSE).

70.4.1 Learning Rules from the View of Precision

CAMLET has been applied to a meningoencephalitis dataset and a medical expert (Prof. Shusaku Tsumoto from Shimane Medical University) have given comments on the rules learned by the inductive applications constructed by CAMLET. Table.70.1 shows us the results of six case studies as mentioned above. This table includes the following items: the case study identification (the first row), the rough specifications of inductive applications constructed by CAMLET (the second row), the best precision of learned rule set (the third row), the number of learned rules judged ordinary (less interesting) (the fourth row), the number of learned rules judged more interesting (the fifth row), the number of learned rules judged difficult to understand (the sixth row) and the number of total learned rules (the last row).

Looking at the specification structures of the inductive applications constructed by CAMLET, although decision tree learning methods, such as ID3 and C4.5, always come up over all the cases, the whole control structures differ at every specification in that ones have bagging and others have boosting, and ones have backward control structures and others not, and so on. Thus CAMLET seems to adapt inductive applications proper to the meningoencephalitis dataset. However, CAMLET cannot support a human expert in discovering interesting knowledge efficiently. We need to introduce heuristics so that the number of interesting rules is larger than that of ordinary rules over all the case studies.

Table 70.1. Experimental Results for Knowledge Discovery

case	rough specification	precision	# of <i>o</i>	# of <i>i</i>	# of <i>l</i>	total
DIAG	Boosting + ID3 + CS	92.1	38	15	0	53
Diag2	Boosting + ID3	100.0	27	8	0	35
CULTURE	Bagging + ID3 (prune)	80.0	48	7	2	57
CULT_FIND	ID3	92.1	18	3	3	24
C_COURSE	Bagging + C4.5 (prune)	85.0	19	3	1	23
COURSE	Bagging + C4.5 (prune)	88.6	39	12	3	54

o means “ordinary rules”.

i means “interesting rules”.

l means “less understandable rules”.

70.4.2 Learning Rules from the View of Specificity

We often bring a default hierarchy in genetic-based machine learning systems such as classifier systems, organizing a set of rules into the hierarchy structure from general rules down to specific rules. On one hand, although general rules cover many instances, they look like the rules with less interest or surprise to human experts. On the other hand, although specific rules cover just a few of instances, they could be the rules with more interest or surprise to them. So, in order to support a human expert in finding out interesting rules, we apply the default hierarchy to rules learned by the inductive applications constructed by CAMLET. This default hierarchy consists of a set of paths from general rules down to specific rules that do not share the same conclusion.

The medical expert gives some comments on four paths from general rules to specific rules in a learned default hierarchy. The first path starts with a general rule on *CULT_FIND* as follow:

$$\begin{aligned}
 &LOC_DAT = + \\
 &\wedge 122.0 \leq CSF_CELL7 \rightarrow CULT_FIND = T \\
 &\quad \textit{precision} : 78.5\% (11/14) \\
 &\quad \textit{recall} : 33.3\% (11/33)
 \end{aligned}$$

This general rule means that *if* a patient has loss of consciousness (*LOC*) and cell count in cerebrospinal fluid seven days after the treatment (*CSF_CELL7*) is more than 122.0, *then* his/her bacteria or virus is found (*CULT_FIND*). This medical expert gives the following comment on this rule: it is all right but not interesting to me.

Getting down to the path and adding the condition of *SEX = M*, the following specific rule comes up:

$$\begin{aligned}
 & LOC_DAT = + \\
 & \wedge 122.0 \leq CSF_CELL7 \\
 & \wedge \underline{SEX = M} \rightarrow CULT_FIND = F \\
 & \quad precision : 100.0\% (3/ 3) \\
 & \quad recall : 2.8\% (3/107)
 \end{aligned}$$

This specific rule means that *if* a patient is a man (underlining) in addition to the previous condition, *then* his/her bacteria or virus is not found. The medical expert gives the following comment on the rule: it seems to be unexpected and interesting to me.

The second path starts with a general rule on *CULT_FIND* as follow:

$$\begin{aligned}
 & \rightarrow CULT_FIND = F \\
 & \quad precision : 76.4\% (107/140) \\
 & \quad recall : 100.0\% (107/107)
 \end{aligned}$$

This general rule means that bacteria or virus is not found from a patient without any conditions in the ratio of 76.4% of cases. The medical expert gives the following comment on this rule: it it all right but not interesting to me.

Getting down to the path and adding the condition of *SEIZURE* < 1.0, the following specific rule comes up:

$$\begin{aligned}
 & \underline{SEIZURE < 1.0} \rightarrow CULT_FIND = T \\
 & \quad precision : 96.9\% (32/33) \\
 & \quad recall : 96.9\% (32/33)
 \end{aligned}$$

The medical expert gives the following comment on this rule: it seems to be unexpected that *if* convulsion or epilepsy (*SEIZURE*) is not observed, *then* it comes to *T*.

The third path starts with a general rule on *COURSE(Grouped)* as follow:

$$\begin{aligned}
 & 42.0 \leq CSF_GLU \rightarrow COURSE(Grouped) = n \\
 & \quad precision : 86.2\% (100/116) \\
 & \quad recall : 85.4\% (100/117)
 \end{aligned}$$

This general rule means that *if* cell count in Glucose (*CSF_GLU*) is above 42.0, *then* clinical course at discharge (*COURSE(Grouped)*) has no symptoms. The medical expert gives the following comment on this rule: it is all right but not interesting to me.

Getting down to the path and adding the condition of $15.0 \leq GCS$, the following specific rule comes up:

$$\begin{aligned}
 & 42.0 \leq CSF_GLU \\
 & \wedge \underline{15.0 \leq GCS} \rightarrow COURSE(Grouped) = p \\
 & \quad precision : 100.0\% (16/16) \\
 & \quad recall : 69.5\% (16/23)
 \end{aligned}$$

This specific rule means that *if* Glasgow Coma Scale (*GCS*), which is a score to evaluate the degree of less of consciousness, is more 15.0, *then* conclusion of a rule is reversed. The medical expert gives the following comment on this rule: it seems to be unclear but open question to me.

The last path starts with a general rule on *COURSE(Grouped)* as follow:

$LOC < 6.0 \rightarrow COURSE(Grouped) = n$
precision : 85.8% (115/134)
recall : 98.2% (115/117)

This general rule means *if* a patient has loss of consciousness (LOC) came to the hospital within six days after LOC was observed, *then* clinical course at discharge (*COURSE(Grouped)*) has no symptoms. The medical expert gives the following comment on this rule: it is all right but not interesting to me.

Getting down to the path and adding the condition of *SEIZURE* < 1.0, the following specific rule comes up:

$LOC < 6.0$
 $\wedge SEIZURE < 1.0 \rightarrow COURSE(Grouped) = p$
precision : 94.7% (18/19)
recall : 78.2% (18/23)

The medical expert gives the following comment on this rule: a combination of conditions seems to be unexpected but open question to me.

Thus some rules learned by the inductive applications constructed by CAMLET come up with medical expert's unexpectedness and interestingness.

70.5 Conclusions and Future Work

In the case studies of knowledge discovery support using a meningoencephalitis dataset, we have evaluated CAMLET from two points of precision and specificity. Especially, in the latter point using a default hierarchy, some learned rules are interesting to a medical expert. Although we get some learned rules that are interesting to a medical expert, too specific rules come up with much less coverage and no interest to him. We will extend the view to evaluate learned rules in order to support human experts in discovery interesting.

Acknowledgement. We have many thanks to Dr. Shusaku Tsumoto who has given us the dataset on meningoencephalitis with his evaluation on the rules generated by our environment.

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71. Extracting Meningitis Knowledge by Integration of Rule Induction and Association Mining

T.B. Ho, S. Kawasaki, and D.D. Nguyen

Japan Advanced Institute of Science and Technology,
Tatsunokuchi, Ishikawa, 923-1292 Japan

71.1 Introduction

The meningitis dataset has been used for extracting meningitis knowledge by learning and mining methods. This paper reports the result of extracting knowledge from this dataset by a novel learning method called LUPC that integrates separate-and-conquer rule induction with association rule mining. We first briefly introduce the basic ideas of LUPC then describe experiments, extracted knowledge and the result evaluation. The extracted knowledge is concerned with factors important for diagnosis (DIAG and DIAG2), for detection of bacteria or virus (CULT_FIND and CULTURE) and for predicting prognosis (C_COURSE and COURSE).

71.2 LUPC: Learning Unbalanced Positive Class

Consider the rule induction problem where we focus on learning a minority target class seen as the positive class C^+ , denoted by *Pos*, and all other classes as the negative class C^- , denoted by *Neg*, i.e., $|Pos| \ll |Neg|$. Denote by $cov(R)$ the set of instances covered by a rule R that is divided into two subsets of covered instances in *Pos* and *Neg*, denoted by $cov(R) = cov^+(R) \cup cov^-(R)$. Our task is to find a set of predictive and descriptive rules for C^+ , denoted by $R^+ = \{R^+_1, R^+_2, \dots, R^+_q\}$ so that $Pos \subseteq cov(R^+_1) \cup cov(R^+_2) \cup \dots \cup cov(R^+_q)$ and the discovered rules are “best” in terms of high sensitivity as well positive predictive value, and low false positive rate. Given thresholds α and β for accuracy and coverage ratio, a rule R is $\alpha\beta$ -strong if $acc(R) \geq \alpha$ and $|cov^+(R)|/|D| \geq \beta$. Table 1 presents the scheme of algorithm LUPC for solving effectively the above problem. There are three essential features of LUPC that make it possible to learn efficiently minority classes in unbalanced datasets. Firstly, it carries out a search biasing alternatively on accuracy and cover ratio with adaptive thresholds. Secondly, it focuses on doing separate-and-conquer induction in the tar

get class with exploitation of the unbalanced property of datasets that allows trying the beam search with a large beam search parameter and one-sided selection. The following property shows the necessary constraint on $\text{cov}^-(R)$ for a rule R to be $\alpha\beta$ -strong in terms of $\text{cov}^+(R)$ and the accuracy threshold. It will be used to reduce time of scanning the large Neg in generating and selecting candidate rules for C^+ : given α , a rule R is not $\alpha\beta$ -strong for any arbitrary β if $\text{cov}^-(R) \geq ((1-\alpha)/\alpha) \times \text{cov}^+(R)$. Thirdly, LUPC integrates pre-pruning and post-pruning in a way that can avoid over-pruning.

Table 1. The scheme of algorithm LUPC

Learn-positive-rule (Pos, Neg, minacc, mincov)	10. return(RuleSet)
1. RuleSet = \emptyset	
2. $\alpha, \beta \leftarrow \text{Initialize}$ (Pos, Neg, minacc, mincov)	Procedure BestRulePos, Neg, α, β
3. while (Pos $\neq \emptyset$ and $(\alpha, \beta) \neq (\text{minacc}, \text{mincov})$)	11. CandidateRuleSet = \emptyset
4. NewRule $\leftarrow \text{BestRule}$ (Pos, Neg, ? \rightarrow)	12. AttributeValuePairs((Pos, Neg, α, β))
5. if (NewRule $\neq \emptyset$)	13. while StopCondition(Pos, Neg, α, β)
6. Pos $\leftarrow \text{Pos} \setminus \text{Cover}^+(\text{NewRule})$	14. CandidateRules(Pos, Neg, α, β)
7. RuleSet $\leftarrow \text{RuleSet} \cup \text{NewRule}$	15. BestRule \leftarrow First CandidateRule in
8. else Reduce (α, β)	CandidateRuleSet
9. RuleSet $\leftarrow \text{PostProcess}$ (RuleSet)	16. return(BestRule)

71.3 Finding Rules from Meningitis Data

We use two methods for discretizing numerical attributes in the meningitis data: entropy-based and rough set-based methods. The entropy-based method often yields few intervals of values, and ignores many attributes (15 out of 38 attributes). The rough set-based method divides continuous attributes into more intervals of values and do not ignore any attributes. From the discretized dataset we created six derived datasets with the corresponding class attribute is from DIAG, DIAG2, CULT_FIND, CULTURE, C_COURSE and COURSE. We run LUPC on each of these datasets on two modes: learning one target class and learning all classes. Experiments have been done with fixed default parameters for finding rules: 95% for minimum accuracy of a rule, 2 cases are minimum cover of a rule, 100 and 30 are numbers of candidate attribute-value pairs and rules, respectively. Different rules were extracted and they are synthesized in nearly 80 tables in the Excel format according to the derived datasets and learning modes, for example:

```

IF      LOC = [*-1) and
        ONSET = ACUTE and
        CSF_CELL = [1505-*) and
        CELL_POLY = [431-*)
THEN   class = BACTERIA [accuracy = 1.00 (12/12); cover = 0.086]

```

Based on synthesized tables of discovered rules, we have provided the domain experts a number of observations and analysis that are commonly concerned with the most frequent attributes in each class, the significant attributes or attribute-value pairs, the significant co-occurred attribute-values pairs, the strong rules with particularly large coverage if available, and rules that may be exceptional.

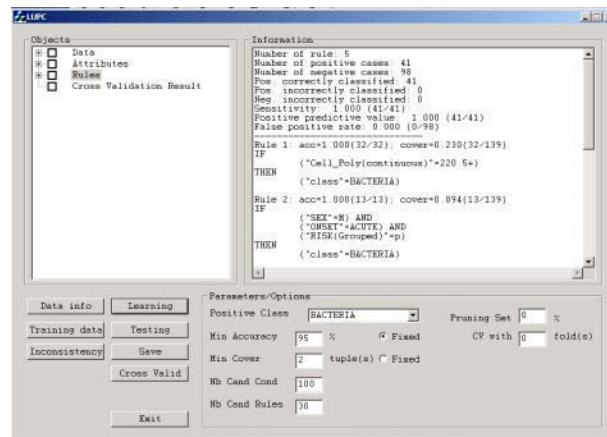


Fig. 1. Finding meningitis knowledge with LUPC

Factors Important for Meningitis Diagnosis DIAG and DIAG2

From discovered rules for DIAG we observed that:

- most frequent attributes: Cell_Poly, Loc_Dat, Egg_Focus, Focal, Ct_Find.
- significant attributes or attribute-value pairs:
 - “Cell_Poly > 220.5” for BACTE(E) and BACTERIA,
 - “Cell_Poly < 220.5” for VIRUS and VIRUS(E),
 - “Egg_Focus = +” for VIRUS(E),
 - “Ct_find = abnormal” for ABSCESS.
- significant co-occurred attribute-values pairs:
 - “Cell_Poly < 220.5” AND “Egg_Focus = -” for VIRUS,
 - “Cell_Poly < 220.5” AND “Focal = +” for VIRUS(E).

And from discovered rule for DIAG2:

- most frequent attributes: Focal, Cell_Poly, Loc_Data, Egg_Focus, Ct_Find.
- significant or discriminant attributes or attribute-value pairs are reconfirmed
 - “Ct_find = abnormal” for ABSCESS,

- “Cell_Poly geq 220.5” for BACTE(E) and BACTERIA,
- “Cell_Poly < 220.5” for VIRUS and VIRUS(E).
- significant co-occurred attribute-values pairs: reconfirmed the above conclusions and some new as “Cell_Poly > 220.5” AND “Onset = Acute” AND “Loc = -1.5” for BACTERIA.
- rules with large coverage: rules for VIRUS
- rules that may be special or typical: rule 1 for ABSCESS, rule 2 for BACTERIA.

A general observation is there are big groups of VIRUS cases that share common symptoms (VIRUS rules with bigger coverage but not very high accuracy) while the rules for BACTERIA are with relatively smaller coverage but higher accuracy. The attribute “ONSET” has high frequency but seems not significant in distinguishing diseases.

Factors for Predicting Prognosis C_COURSE and COURSE

From discovered rules for C_COURSE we observed that:

- most frequent attributes: Lasegue, Focal, Loc_Dat, Onset Ct_Find.
- significant or discriminant attributes or attribute-value pairs:
 - for class “dead”: Locdat = +”, “Egg_wave = abnormal”,
 - for class “negative”: “Onset = Acute”, “Lasegue = 0”, “Focal = -”, “Cell_Mono > 10”.
- significant co-occurred attribute-values pairs:
 - “Cell_Mono < 10” AND “Locdat = +” for class “dead”,
 - “Egg_wave = abnormal” AND “Locdat = +” for class “dead”,
 - “Kernig = 0” AND “Focal = -” AND “Crp < 4.8” for class “negative”,
 - “Kernig = 0” AND “Focal = -” AND “Csf_Cell in (30.5-1040)” for class “negative”.
- rules with large coverage: rules from 5 to 17 for class “negative”.
- rules that may be special or typical: all rules for class “dead”, rule 23 for class “negative”.

And form rules for COURSE:

- most frequent attributes: Lasegue, Focal, Locdat.
- significant or discriminant attributes or attribute-value pairs:
 - “Focal = -” in class “n” and “Focal = +” in class “p”,
 - “Locdat = -” in class “n” and “Locdat = +” in class “p”,
 - “Egg_wave = normal” in class “n”, “Egg_wave = abnormal” in “p”,
 - “Cell_Mono > 10” in class “n” and “Cell_Mono < 10” in class “p”
 - “Lasegue = 0” is popular in class “n”.
- significant co-occurred attribute-values pairs:
 - “Lasegue = 0” AND “Focal = -” AND “Crp < 4.8” in class “n”,
 - “Lasegue = 0” AND “Cell_Mono > 1.0” in class “n”,

- “Local = +” AND “Focal = +” AND “Egg_wave = abnormal” in “p”,
- “Locdat = +” AND “Cell_Mono < 1.0” in class “p”.
- rules with large coverage: most rules for class “n”.

Two classes “n” and “p” can be distinguished by obtained rules.

Detection of Bacteria or Virus: CULTURE and CULT_FIND

From discovered rules for CULTURE we observed that:

- most frequent attributes: Loc_Dat, Crp, Ct_Find, Csf_Cell.
- significant or discriminant attributes or attribute-value pairs:
 - “Locdat = -”, “Crp < 4.8”, “Cell_Mono > 10” are popular in class “-”,
 - “Egg_wave = abnormal”, Ct_find = abnormal” are popular in classes “hepes” and “strepto”
- significant co-occurred attribute-values pairs:
 - “Locdat = -” AND “Crp < 4.8” AND “Cell_Mono > 10” in class “-”,
 - “Egg_wave = abnormal” AND “Ct_find = abnormal” OR “Egg_wave = abnormal” AND “Risk = sinusitis” in class “strepto”.
- rules with large coverage: most rules for class “-”.

And from rules for CULTFIND:

- most frequent attributes: Loc_Dat, Egg_Focus, Csf_Cell, Cf_Find, Risk.
- significant or discriminant attributes or attribute-value pairs:
 - “Locdat = -” is popular in “F” while “Locdat = +” is popular in “T”,
 - “Crp < 4.8” is popular in “F” while “Crp > 4.8” is popular in “T”,
 - “Cell_Mono > 10” is popular in “F” while “Cell_Mono < 10” is popular in “T”,
 - “Ct_find = normal” is popular in “F” while “Ct_find = abnormal” is popular in “T”,
 - “Risk = p” is popular in “F” while “Risk = n” OR “Risk = sinusitis” are popular in “T”.
- significant co-occurred attribute-values pairs:
 - “Onset = acute” AND “Crp < 4.8” in “F”,
 - “LocDat = +” AND “Risk = n” in “T”.

71.4 Conclusion

We have briefly introduced method LUPC to learn the target positive class from large unbalanced datasets. The essence of LUPC is its combination of separate-and-conquer rule induction with association rules mining, as well the use of dynamic multiple thresholds and the property of unbalanced datasets. We apply LUPC to investigate the meningitis dataset. Many rules with high accuracy have been found for factors important for diagnosis (DIAG and DIAG2), for detection

of bacteria or virus (CULT_FIND and CULTURE) and for predicting prognosis (C_COURSE and COURSE). Appendixes 1 and 2 present a summarization of rules extracted for DIAG.

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Appendix 1

LUPC's rule learning includes two modes: learning all classes and learning only one target class. These four tables show the numbers of cases which covered rules from "DIAG2" and "DIAG" obtained by LUPC with the condition of: (1) learning mode: all classes, (2) Minimum accuracy: 95%, (3) Minimum cover: 2 cases, (4) Number candidate conditions: 100, (5) Number candidate rules: 30. Table 2 is the result on "DIAG2" discretized by entropy. Table 3 is the result on "DIAG2" discretized by Rosetta. Likewise, Table 4 and Table 5 are the results on "DIAG2" discretized by entropy and Rosetta.

Table 2. Rules from "diag2" discretized by entropy

class	ID	(a)	(b)	(c)	(d)
BACTERIA	1	1.00	32	32	0.23
BACTERIA	2	1.00	13	13	0.09
BACTERIA	3	1.00	12	12	0.09
BACTERIA	4	1.00	11	11	0.08
BACTERIA	5	1.00	8	8	0.06
VIRUS	6	0.95	100	95	0.72
VIRUS	7	0.97	88	85	0.63
VIRUS	8	0.99	83	82	0.60
VIRUS	7	0.97	88	85	0.63
VIRUS	8	0.99	83	82	0.60

(a) : accuracy
 (b) : number of covered cases
 (c) : number of correct cases
 (d) : coverage of the rule

Table 3. Rules from "diag2" discretized by Rosetta

class	ID	(a)	(b)	(c)	(d)
BACTERIA	1	1.00	27	27	0.19
BACTERIA	2	1.00	15	15	0.11
BACTERIA	3	1.00	14	14	0.10
BACTERIA	4	1.00	12	12	0.09
BACTERIA	5	1.00	9	9	0.06
BACTERIA	6	1.00	9	9	0.06
BACTERIA	7	1.00	9	9	0.06
BACTERIA	8	1.00	5	5	0.04
VIRUS	9	0.96	47	45	0.34
VIRUS	10	0.96	45	43	0.32
VIRUS	11	0.96	45	43	0.32
VIRUS	12	0.96	45	43	0.32
VIRUS	13	0.95	44	42	0.31
VIRUS	14	0.95	43	41	0.31
VIRUS	15	0.95	42	40	0.30
VIRUS	16	0.95	42	40	0.30
VIRUS	17	0.95	40	38	0.29
VIRUS	18	0.97	32	31	0.23
VIRUS	19	0.97	32	31	0.23
VIRUS	20	0.97	29	28	0.21
VIRUS	21	0.96	28	27	0.20
VIRUS	22	0.96	27	26	0.19
VIRUS	23	0.96	26	25	0.19
VIRUS	24	1.00	23	23	0.16
VIRUS	25	0.96	23	22	0.16
VIRUS	26	0.96	23	22	0.16

Table 4. Rules from "diag" discretized by entropy

class	ID	(a)	(b)	(c)	(d)
ABSCCESS	1	1.00	6	6	0.04
ABSCCESS	2	1.00	3	3	0.02
ABSCCESS	3	1.00	2	2	0.01
ABSCCESS	4	1.00	2	2	0.01
BACTE(E)	5	1.00	3	3	0.02
BACTE(E)	6	1.00	2	2	0.01
BACTE(E)	7	1.00	2	2	0.01
BACTERIA	8	1.00	11	11	0.08
BACTERIA	9	1.00	10	10	0.07
BACTERIA	10	1.00	8	8	0.06
BACTERIA	11	1.00	8	8	0.06
BACTERIA	12	1.00	8	8	0.06
BACTERIA	13	1.00	6	6	0.04
BACTERIA	14	1.00	5	5	0.04
VIRUS	15	0.95	61	58	0.44
VIRUS	16	0.95	60	57	0.43
VIRUS	17	0.97	58	56	0.41
VIRUS	18	0.96	54	52	0.39
VIRUS	20	0.95	43	41	0.31
VIRUS	19	0.96	51	49	0.36
VIRUS(E)	21	1.00	11	11	0.08
VIRUS(E)	22	1.00	11	11	0.08
VIRUS(E)	23	1.00	10	10	0.07
VIRUS(E)	24	1.00	9	9	0.06
VIRUS(E)	25	1.00	9	9	0.06
VIRUS(E)	26	1.00	8	8	0.06
VIRUS(E)	27	1.00	6	6	0.04
VIRUS(E)	28	1.00	7	7	0.05

Table 5. Rules from "diag" discretized by Rosetta

class	ID	(a)	(b)	(c)	(d)
ABSCCESS	1	1.00	6	6	0.04
ABSCCESS	2	1.00	4	4	0.03
ABSCCESS	3	1.00	4	4	0.03
ABSCCESS	4	1.00	4	4	0.03
BACTE(E)	5	1.00	3	3	0.02
BACTE(E)	6	1.00	3	3	0.02
BACTE(E)	7	1.00	3	3	0.02
BACTE(E)	8	1.00	3	3	0.02
BACTE(E)	9	1.00	2	2	0.01
BACTE(E)	10	1.00	2	2	0.01
BACTERIA	11	1.00	12	12	0.09
BACTERIA	12	1.00	9	9	0.06
BACTERIA	13	1.00	8	8	0.06
BACTERIA	14	1.00	7	7	0.05
BACTERIA	15	1.00	7	7	0.05
BACTERIA	16	1.00	6	6	0.04
BACTERIA	17	1.00	6	6	0.04
BACTERIA	18	1.00	6	6	0.04
BACTERIA	19	1.00	5	5	0.04
BACTERIA	20	1.00	5	5	0.04
BACTERIA	21	1.00	4	4	0.03
VIRUS	22	0.95	22	21	0.16
VIRUS	23	0.95	21	20	0.15
VIRUS	24	0.95	21	20	0.15
VIRUS	25	0.95	21	20	0.15
VIRUS	26	0.95	20	19	0.14
VIRUS	27	1.00	18	18	0.13
VIRUS	28	1.00	15	15	0.11
VIRUS	29	1.00	15	15	0.11
VIRUS	30	1.00	14	14	0.10
VIRUS	31	1.00	14	14	0.10
VIRUS	32	0.97	33	32	0.24
VIRUS(E)	33	1.00	10	10	0.07
VIRUS(E)	34	1.00	10	10	0.07
VIRUS(E)	35	1.00	9	9	0.06
VIRUS(E)	36	1.00	9	9	0.06
VIRUS(E)	37	1.00	9	9	0.06
VIRUS(E)	38	1.00	7	7	0.05
VIRUS(E)	39	1.00	7	7	0.05
VIRUS(E)	40	1.00	7	7	0.05
VIRUS(E)	41	1.00	7	7	0.05
VIRUS(E)	42	1.00	7	7	0.05
VIRUS(E)	43	1.00	6	6	0.04
VIRUS(E)	44	1.00	6	6	0.04
VIRUS(E)	45	1.00	6	6	0.04

72. Basket Analysis on Meningitis Data

Takayuki Ikeda, Takashi Washio, and Hiroshi Motoda

Institute of Scientific and Industrial Research, Osaka University,
8-1, Mihogaoka, Ibarakishi, Osaka, 567-0047, JAPAN

Basket Analysis is the most representative approach in recent study of data mining. However, it cannot be directly applied to the data including numeric attributes. In this paper, we propose an algorithm and performance measures for the selection and the discretization of numeric attributes in the data preprocessing stage for the wider application of Basket Analysis, and the performance is evaluated through the application to the meningitis data.

72.1 Introduction

Basket Analysis is the most representative approach in the study of data mining[72.1], and has become to be widely used in the real world applications in recent years. Based on this background, we decided to apply Basket Analysis to the meningitis data given in this discovery challenge[72.2]. However, Basket Analysis has a drawback that it cannot handle data involving numeric information such as the meningitis data, because it is to mine the associations among discrete events in principle. Thus, the task to select numeric attributes having associations with other attributes and to discretize the values of the selected numeric attributes in the data must be introduced to the mining process. An approach is to embed the task into the mining algorithm. This approach is taken in the decision tree based mining such as C4.5[72.3]. The mining algorithm directly accepts the numeric data, selects attributes relevant to the class, and discretizes the values of the selected numeric attributes while developing the decision tree. However, this approach is not suitable for Basket Analysis since its algorithm does not include any process of intermediate estimation of value distributions for massive data.

Accordingly, we followed another approach, which applies the selection and the discretization in the data preprocessing stage. One important issue in its development is that the selection of the numeric attributes must be performed while taking into account the dependency among the attributes. This is because the association is a representation of the strong dependency among the events characterized by the attributes. The second issue is that the points of the discretizations in the value ranges of the numeric attributes must be chosen to appropriately reflect the dependency of the data distribution among multiple attributes. The third issue is that the discretization must have appropriate granularity. If the granularity is too small, the excessive fragmentation of the dependent region reduces the number of data representing the association of the values in each fragmented region.

The fourth issue is to establish an efficient algorithm for the selection and the discretization under massive data, though this issue is not crucial for the meningitis data since the number of the data is very limited.

The objectives of this paper are as follows.

- (1) Development of an approach for the selection and the discretization of numeric attributes addressing the aforementioned four issues.
- (2) Application of the approach and Basket Analysis to the meningitis data, the evaluation of their performance and the discussion on the discovered knowledge.

72.2 Method for Selection and Discretization

72.2.1 Algorithm

First, the algorithm to select and discretize the numeric attributes we developed is described [72.4]. The entire flow chart of the algorithm is depicted in Fig. 72.1. Given a performance measure, this algorithm takes the greedy strategy to conduct the selection and discretization for large database in an efficient manner, and thus does not ensure to achieve the optimum selection and discretization. The detail of the performance measure will be described in the later subsection.

Initially the minimum value in the value range of data for a numeric attribute is set to be a candidate threshold value. Applying this threshold for the discretization, its performance is evaluated, and it is compared with the performance of the former candidate threshold if it exists. When the performance of the newest candidate threshold is better, the threshold and the performance are recorded. Increasing the threshold value in some small amount, this search process is repeated until all candidate thresholds for every attribute have been evaluated. Once this repetition is finished, the attribute and its threshold value having the optimum performance is selected and used to discretize the data at the threshold of the attribute. After determining the threshold value of a numeric attribute, the search of another attribute and its threshold is repeated until the number of the threshold becomes to a given upper limit. The process of the selection and the discretization is applied only to the numeric attributes in the data, and the discretized attribute is merged with the original categorical attribute. As easily seen by the loop structure of the algorithm, this algorithm needs only the computational time in the order of $O(ND)$ where N and D are the number of data and the number of numeric attributes. Because of the linear order of the computational time in terms of the data size, this algorithm can process a large amount of data efficiently, and hence the issue of the efficiency described in the first section is addressed by this algorithm.

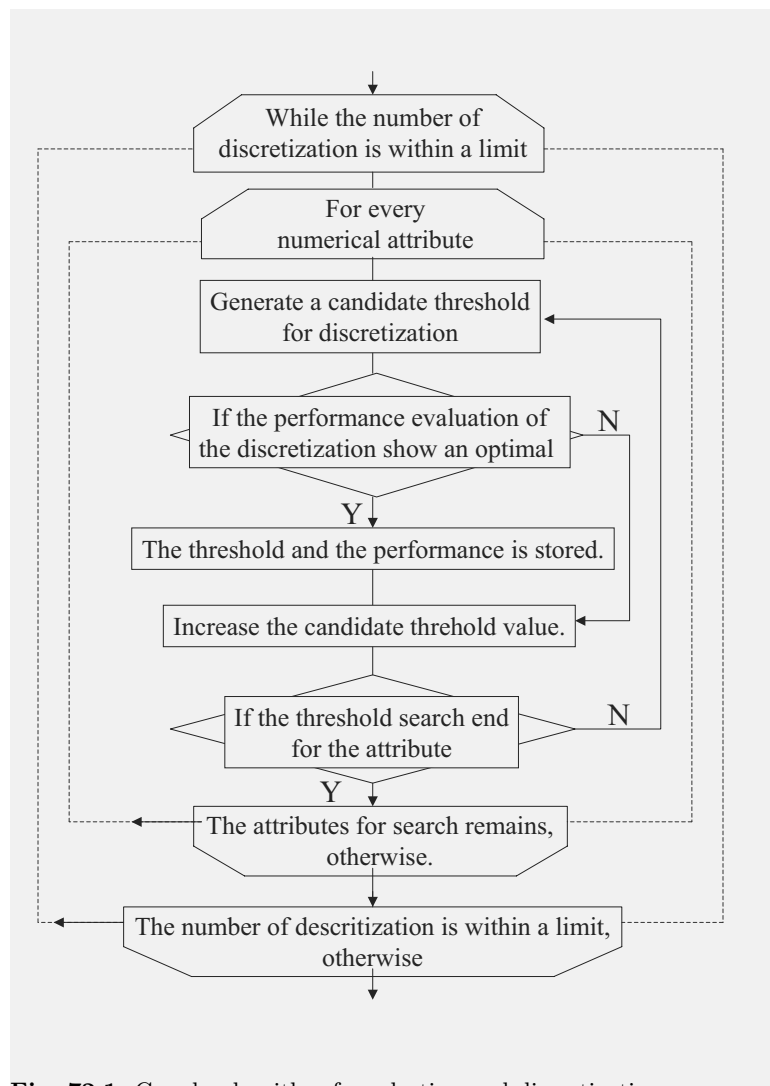


Fig. 72.1. Greedy algorithm for selection and discretization.

72.2.2 Performance Measure

The most representative performance measure is the information entropy evaluated from the class distribution of data on each numeric attribute axis. This measure is used in the selection and the discretization scheme of C4.5[72.3]. However, this measure cannot take into account the dependency of the class distribution among multiple numeric attributes since the selection and the discretization is applied to each attribute individually. Accordingly, the performance measure based on the class distribution in each region space gene-

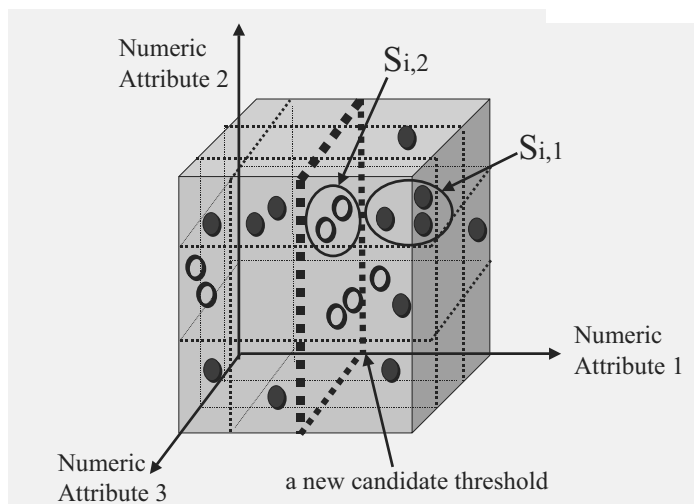


Fig. 72.2. Regions and class distribution.

rated by the discretization is used in our work. The distribution $S_{i,j}$ of the data having class $j(= 1, 2)$ in a region i is depicted in Fig.72.2. In this figure, $|S_{i,1}| = 3$ and $|S_{i,2}| = 2$. Based on total distribution of $|S_{i,j}|$ s, the performance measure such as the information entropy of the entire discretization can be calculated.

However, the information entropy based on the discretized region space does not suggest the appropriate number of the attributes and their thresholds for the selection and the discretization. Therefore, it does not address the issue of the granularity described in the first section. This difficulty is solved by introducing the well-known measure named AIC (Akaike's Information Criterion) which represents Kullback information entropy[72.5]. Given a discretization pattern HT , AIC under HT is evaluated by following.

$$AIC(HT) = -2 \sum_{i=1}^M |S_i| \sum_{j=1}^{K_i} \frac{|S_{i,j}|}{|S_i|} \log \frac{|S_{i,j}|}{|S_i|} + 2\alpha, \quad (72.1)$$

where M is the total number of the discretized regions containing some data, $|S_i|$ the number of the data in the i -th region, K_i the number of the classes appearing in the i -th region, $|S_{i,j}|$ the number of the data having the j -th class in the i -th region, and α the number of thresholds in HT . This measure can estimate the discretization having an appropriate granularity, which does not fragment the dependent regions among attributes under the assumption that rectangular parallelepipeds indicated in Fig.72.2 can asymptotically subsume each dependent region. However, this assumption does not always hold, since the shapes of the dependent regions are not limited to parallelepipeds. Hence we sought the other measure to address the granularity issue.

The principle of the performance measure proposed in this work is the Minimum Description Length (MDL) principle[72.6]. The description length used in this work, $Length(HT)$, is the sum of the description length of a discretization pattern HT , i.e., code book length, and the description length of the class information of the given data under HT , i.e., coding length. The formula of $Length(HT)$ depends on the coding method of the class information. When the combination of the classes appearing in each discretized region is coded, the formula becomes as follows.

$$\begin{aligned}
 Length(HT) = & - \sum_{i=1(|S_i| \neq 0)}^M \sum_{j=1}^{K_i} (|S_{i,j}| + 1) \cdot \log_2 \frac{|S_{i,j}| + 1}{|S_i| + K_i} \\
 & + \sum_{n=1}^D \left\{ -(\alpha + 1) \cdot \log_2 \frac{\alpha + 1}{|T_n| + 2} - (|T_n| - \alpha + 1) \cdot \log_2 \frac{|T_n| - \alpha + 1}{|T_n| + 2} \right\} \\
 & + M \cdot \log_2(2^K - 1), \tag{72.2}
 \end{aligned}$$

where $|T_n|$ is the number of candidate thresholds for the n -th attribute and K the total number of the classes. When the codes are assigned to all classes even if some classes do not appear in a discretized region, the combination of the classes does not have to be coded. Thus, we obtain the following formula.

$$\begin{aligned}
 & Length(HT) \\
 = & - \sum_{i=1(|S_i| \neq 0)}^M \sum_{j=1}^K (|S_{i,j}| + 1) \cdot \log_2 \frac{|S_{i,j}| + 1}{|S_i| + K} \\
 & + \sum_{n=1}^D \left\{ -(\alpha + 1) \cdot \log_2 \frac{\alpha + 1}{|T_n| + 2} - (|T_n| - \alpha + 1) \cdot \log_2 \frac{|T_n| - \alpha + 1}{|T_n| + 2} \right\}. \tag{72.3}
 \end{aligned}$$

MDL principle suggests that the selection and the discretization pattern which gives the minimum $Length(HT)$ is the best in terms of the parsimonious description of the data. Eq.(72.1), Eq.(72.2) and Eq.(72.3) are applied to the algorithm of Fig.72.1 as the performance measures respectively.

72.3 Application

The meningitis data provided in this JKDD01 Challenge contain 140 cases consisting of 21 numeric attributes and 13 categorical attributes. They represent the contents of medical examination, inspection and treatment. The data also include two class attributes on the diagnosis result, DIAG and DIAG2. We applied our approach to the class DIAG which takes 6 values. The objectives of the mining analysis are as follows.

- (a) To obtain association rules which indicate the conditions of the class DIAG.
- (b) To obtain association rules describing the relations among multiple attributes.

- (c) To compare the empirical characteristics of the three performance measures.
- (d) To obtain the review on the mining results by a medical expert and to reflect the review comments to the further analyses and discussions.

The procedure of the analysis consists of the following five stages. First, the aforementioned selection and discretization method is applied to the numeric attributes except CSF_CELL3 containing some missing values. Thus, the selection and the discretization are applied to the 20 numeric attributes. Second, the categorical attributes except THERAPY2 representing the treatment method, i.e., totally 12 attributes, are combined with the discretized attributes. THERAPY2 was removed because the treatment is a consequence of the diagnosis but not a condition. Third, each attribute and its value are combined together, and it is transformed into the form of an item. This is because the original data have a table format, but Basket Analysis in the later stage accepts only the data in an item transaction format. Forth, Basket Analysis is applied to the data preprocessed in the former stages. Fifth, the association rules containing the class attribute DIAG in the head part are collected for the aforementioned object (a). The other rules are separately collected for the object (b). Every performance measure of Eq.(72.1), Eq.(72.2) and Eq.(72.3) is applied to this mining process.

72.4 Result and Expert's Evaluation

Table 72.1 shows the attributes and their threshold values derived through the selection and discretization process by each performance measure. AIC Eq.(72.1) selects and discretizes only a small number of attributes, but the selection of the attributes has some variety. MDL Eq.(72.2) selects and discretizes many attributes, but does not show much variety in the attribute selection. MDL Eq.(72.3) selects and discretizes attributes as many as MDL Eq.(72.2). This may be because of the similarity of the criterion formulae. However, the discretized attributes show much variety in MDL Eq.(72.3). The value of Eq.(72.2) has a high sensitivity to the number of the classes included in each region, because the combination of the classes appearing in each region is coded in the measure, and the number of the combination is exponential to the number of the classes. The sensitivity makes the class distribution in each region to be dominated by a class, and reduces the chance to discretize a region including various classes where the regions dominated by a class are hardly obtained by the discretization. Accordingly, the region already dominated by a class has a tendency to be further selected and discretized on the attributes, which have been already used for the discretization.

By applying the subsequent stages for the three performance measures, we obtained dozens of association rules. They are presented to the medical expert who provided this data. The expert suggested that the attribute RISK(Grouped) should be removed from the data, since it is generated by

Table 72.1. Discretized attributes and threshold values

m	AIC Eq.(72.1)		MDL Eq.(72.2)		MDL Eq.(72.3)	
	attributes	thresholds	attributes	thresholds	attributes	thresholds
1	Cell_Poly	2210	Cell_Poly	307.9	Cell_Poly	307.9
2	Cell_Mono	12.0	CSF_CELL	33.8	Cell_Mono	83.3
3	CRP	3.1	Cell_Poly	131.6	FEVER	7.0
4	Cell_Mono	320.0	SEIZURE	1.86	AGE	46.2
5	HEADACHE	3.0	Cell_Poly	6935.2	NAUSEA	4.0
6	CSF_GLU	55.0	CSF_CELL	8468.4	CSF_PRO	44.2
7	BT	37.0	Cell_Poly	657.8	Cell_Poly	55.2
8	-	-	Cell_Poly	2115.7	LOC	0.0013
9	-	-	CSF_CELL	2668.3	HEADACHE	5.0
10	-	-	Cell_Poly	55.2	WBC	6846.9
11	-	-	WBC	19680.8	BT	37.8
12	-	-	CSF_CELL	84.7	CSF_GLU	49.0
13	-	-	CSF_GLU	108.8	Cell_Poly	2.6
14	-	-	Cell_Poly	28.9	Cell_Poly	7.6
15	-	-	Cell_Mono	117.8	Cell_Poly	15.9

grouping the values of another attribute RISK, and shares some redundant information with RISK. After its removal, the mining process is repeated. The followings are the examples of the sets of association rules containing the class attribute DIAG in the head part derived by the second mining process under some minimum support and minimum confidence levels.

AIC Eq.(72.1): Minimum Support=45% and Minimum Confidence=60%

```
{[LOC_DAT] : -} ==> {[CRP] : under3.1, [Cell_Poly] : under221, [DIAG] : VIRUS}
{[LOC_DAT] : -} ==> {[Cell_Poly] : under221, [CT_IND] : normal, [DIAG] : VIRUS}
{[LOC_DAT] : -} ==> {[Cell_Poly] : under221, [RISK] : n, [DIAG] : VIRUS}
{[Cell_Poly] : under221, [RISK] : n} ==> {[CRP] : under3.1, [DIAG] : VIRUS}
{[Cell_Poly] : under221, [RISK] : n} ==> {[DIAG] : VIRUS, [LOC_DAT] : -}
{[Cell_Poly] : under221, [RISK] : n} ==> {[DIAG] : VIRUS, [FOCAL] : -}
{[Cell_Poly] : under221, [RISK] : n} ==> {[DIAG] : VIRUS, [COURSE] : negative}
{[Cell_Poly] : under221} ==> {[CRP] : under3.1, [DIAG] : VIRUS}
{[Cell_Poly] : under221} ==> {[DIAG] : VIRUS, [LOC_DAT] : -}
{[Cell_Poly] : under221} ==> {[DIAG] : VIRUS, [FOCAL] : -}
{[Cell_Poly] : under221} ==> {[DIAG] : VIRUS, [COURSE] : negative}
{[Cell_Poly] : under221, [COURSE] : negative} ==> {[DIAG] : VIRUS, [COURSE(Grouped)] : n}
{[Cell_Poly] : under221, [COURSE(Grouped)] : n} ==> {[DIAG] : VIRUS, [COURSE] : negative}
```

MDL Eq.(72.2): Minimum Support=45% and Minimum Confidence=60%

```
{[LOC_DAT] : -} ==>
{[DIAG] : VIRUS, [SEIZURE] : under1.85, [WBC] : under19680, [CSF_GLU] : under108}
{[FOCAL] : -} ==>
{[DIAG] : VIRUS, [SEIZURE] : under1.85, [WBC] : under19680, [CSF_GLU] : under108}
{[CT_IND] : normal} ==> {[DIAG] : VIRUS, [SEIZURE] : under1.85, [CSF_GLU] : under108}
{[SEIZURE] : under1.85, [Cell_Mono] : over17.7} ==> {[DIAG] : VIRUS, [CSF_GLU] : under108}
{[Cell_Mono] : over17.7, [ONSET] : ACUTE, [RISK] : n} ==>
{[DIAG] : VIRUS, [SEIZURE] : under1.85, [CSF_GLU] : under108}
{[Cell_Mono] : over17.7, [ONSET] : ACUTE} ==>
{[DIAG] : VIRUS, [SEIZURE] : under1.85, [CSF_GLU] : under108, [RISK] : n}
{[SEIZURE] : under1.85, [Cell_Mono] : over17.7, [CSF_GLU] : under108, [RISK] : n} ==>
{[DIAG] : VIRUS, [WBC] : under19680}
{[SEIZURE] : under1.85, [Cell_Mono] : over17.7, [CSF_GLU] : under108, [RISK] : n} ==>
{[DIAG] : VIRUS, [ONSET] : ACUTE}
```



```

{{SEIZURE} : under1.85, [CellMono] : over17.7, [CSFGLU] : under108} ==>
  {{DIAG} : VIRUS, [WBC] : under19680, [RISK] : n}
{{SEIZURE} : under1.85, [CellMono] : over17.7, [CSFGLU] : under108} ==>
  {{DIAG} : VIRUS, [ONSET] : ACUTE}
{{SEIZURE} : under1.85, [CSFGLU] : under108, [ONSET] : ACUTE, [RISK] : n} ==>
  {{DIAG} : VIRUS}
{{SEIZURE} : under1.85, [CSFGLU] : under108, [ONSET] : ACUTE} ==> {{DIAG} : VIRUS}

```

MDL Eq.(72.3): Minimum Support=45% and Minimum Confidence=60%

```

{{LOC} : under0.0013} ==> {{DIAG} : VIRUS}
{{LOC_DAT} : -} ==> {{DIAG} : VIRUS, [CTFIND] : normal}
{{LOC_DAT} : -} ==> {{DIAG} : VIRUS, [RISK] : n}
{{FOCAL} : -} ==> {{DIAG} : VIRUS, [RISK] : n}
{{CTFIND} : normal} ==> {{DIAG} : VIRUS[LOC_DAT] : -}
{{COURSE} : negative} ==> {{DIAG} : VIRUS}

```

The contents of the mined rule sets show the strong dependency on the performance measures. In case of MDL Eq.(72.2), many rules have mutually similar body parts and/or head parts which are derived from almost identical frequent itemsets except the first three rules. The first three rules are also derived from mutually similar frequent itemsets. The reason why only similar frequent itemsets are derived is because the discretization of MDL Eq.(72.2) does not show much variety in the attribute selection as pointed out earlier. The case of AIC Eq.(72.1) also shows the similar tendency. Because the number of the numeric attributes selected and discretized by this performance measure is small as shown in Table 72.1, the number of the frequent itemsets found in Basket Analysis becomes small. This effect also reduces the variety of frequent itemsets derived in Basket Analysis. On the other hand, the case of MDL Eq.(72.3) shows more variety of the combinations of the items appearing within a small number of rules. This is because the variety and the number of the attributes selected and discretized by this performance measure were large as mentioned earlier. In addition, the number of itemsets included in each rule is smaller than the other cases. This is also due to the large variety and the large number of the discretized attributes. This property of the selection and the discretization increases the number of the discretized regions in the numeric attribute space, and the number of the data in a region is reduced. This effect makes the size of the frequent itemsets smaller. Almost identical tendency has been observed for the association rules describing the relations among multiple attributes excluding the class attribute. They are not indicated due to the space limitation.

72.5 Conclusion

The medical experts evaluated the rule sets derived by using MDL Eq.(72.3) contains more interesting rules than the other cases. He ordered the performance measures in terms of the ability to derive interesting rules as follows.

$$MDLEq.(72.3) > MDLEq.(72.2) > AICEq.(72.1) \quad (72.4)$$

This order matches with the order of the variety of itemset combinations in the association rules. The set of rules among various attributes and their thresholds suggests many potential mechanisms underlying the data.

In conclusion, the performance measure for the discretization of the numeric attributes' values strongly affects the results of Basket Analysis. The performance measure which selects variety of the attributes and many threshold values catches interesting relations among events for domain experts. This insight should be validated through the extensive analysis in the future.

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73. Extended Genetic Programming Using Apriori Algorithm for Rule Discovery

Ayahiko Niimi and Eiichiro Tazaki

Department of Control and Systems Engineering,
Toin University of Yokohama
1614 Kurogane-cho, Aoba-ku, Yokohama 225-8502, JAPAN
tazaki@intlab.toin.ac.jp

Genetic programming (GP) usually has a wide search space and can use tree structure as its chromosome expression. So, GP may search for global optimum solution. But, in general, GP's learning speed is not so fast. Apriori algorithm is one of algorithms for generation of association rules. It can be applied to large database. But, It is difficult to define its parameters without experience. We propose a rule discovery technique from a database using GP combined with association rule algorithm. It takes rules generated by the association rule algorithm as initial individual of GP. The learning speed of GP is improved by the combined algorithm. To verify the effectiveness of the proposed method, we apply it to the meningoencephalitis diagnosis activity data in a hospital. We got domain expert's comments on our results. We discuss the result of proposed method with prior ones.

73.1 Introduction

Various techniques have been proposed for rule discovery using classification learning. In general, the learning speed of a system using genetic programming (GP) [73.1] is slow. However, a learning system which can acquire structural knowledge by adjusting to the environment can be constructed, because GP's chromosome expression is tree structure, and the structure is evaluated by fitness value for the environment.

On the other hand, there is the Apriori algorithm [73.2], a rule generating technique for large databases. This is an algorithm for generation of association rules. The Apriori algorithm uses two indices for rule construction: a support value and a confidence value. Depending on the setting of each index threshold, the search space can be reduced. However, it is possible that an unexpected rule cannot be extracted by reducing the range of the search space. Moreover, the load of the expert who analyzes the rule increases when there are a lot of association rule candidates, and it is a possible that it becomes difficult to search for a useful rule. Some experience is necessary to set an effective threshold.

Both techniques have advantages and disadvantages as above. In this paper, we propose an extended genetic programming using apriori algorithm for rule discovery. By using the combined rule generation learning method,

it is expected to construct a system which can search for high accurate rules in large databases. The purpose of this research is achieving high forecast accuracy by small number of rules.

73.2 Genetic Programming

Genetic programming (GP) is a learning method based on the natural theory of evolution, and the flow of the algorithm is similar to genetic algorithm (GA). The difference between GP and GA is that GP has extended its chromosome to allow structural expression using function nodes and terminal nodes. [73.1] In this paper, the tree structure is used to express the decision tree.

The decision tree construction by GP follows the following procedures.

1. An initial population is generated from a random grammar of the function nodes and the terminal nodes defined for each problem domain.
2. The fitness value, which relates to the problem solving ability, for each individual of the GP population is calculated.
3. The next generation is generated by genetic operations.
 - a) The individual is copied according to the fitness value (reproduction).
 - b) A new individual is generated by intersection (crossover).
 - c) A new individual is generated by random change (mutation).
4. If the termination condition is met, then the process ends. Otherwise, the process repeats from the calculation of fitness value in step 2.

Generally, there is no method of adequately controlling the growth of the tree, because GP does not evaluate the size of the tree. Therefore, during the search process the tree may become overly deep and complex, or may settle to a too simple tree. The technique by which GP defines an effective partial tree is proposed. The approach is automatic function definition (or Automatically Defined Function: ADF), and this is achieved by adding the gene expression for the function definition to normal GP [73.4]. By implementing ADF, a more compact program can be produced, and the number of generation cycles can be reduced. More than one gene expression of ADF can be defined in one individual.

One example of our GP expression is shown following. (See Figure 73.1)

In Figure 73.1, decision tree is expressed in the form similar to LISP-code. GP-TREE expresses one individual of GP, and GP-TREE is composed of the ADF definition part and the main tree part. "RPB" defines main GP tree. Both "ADF0" and "ADF1" defined as each ADF tree. "IFLTE", "IFEQ" are function nodes. These functions requires four arguments (in following example, we use $arg1, arg2, arg3, arg4$). The definitions of them are following.

(IFLTE $arg1, arg2, arg3, arg4$) if $arg1$ is less than or equal to (\leq) $arg2$ then evaluate $arg3$, else then evaluate $arg4$

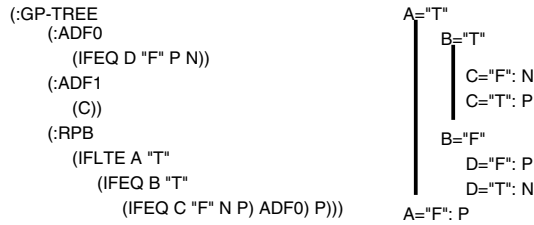


Fig. 73.1. Expression of GP’s Chromosome (The left side is an individual expression of LISP-code and the right side is rewritten to the decision tree expression.)

(IFEQ *arg1, arg2, arg3, arg4*) if *arg1* is equal to(=) *arg2* then evaluate *arg3*, else then evaluate *arg4*.

A, B, C and D express the attributes in database. “T” and “F” express attribute value, and “N” and “P” express class name.

73.3 Approach of Proposed Combined Learning

To make up for the advantage and the disadvantages of the Apriori algorithm and GP, we propose a rule discovery technique which combines GP with the Apriori algorithm. By combining each technique, the search of high accurate rules from a large database is expected. An outline of our proposed technique is shown in Figure 73.2.

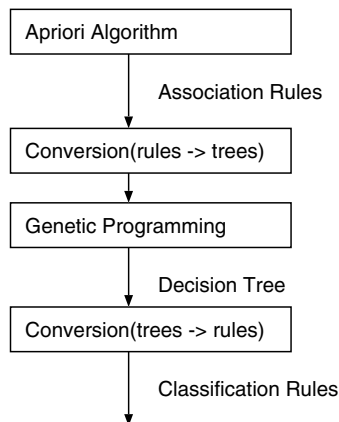


Fig. 73.2. Flow Chart of Approach of Proposed Combined Learning

The following steps are proposed for the rule discovery technique.

1. First, the Apriori algorithm generates the association rule.
2. Next, the generated association rules are converted into decision trees which are taken in as initial individuals of GP. The decision trees are trained by GP learning.
3. The final decision tree is converted into classification rules.

This allows effective schema to be contained in the initial individuals of GP. As a result, it is expected to improve the GP's learning speed and its classification accuracy. However, when GP is used for multi-value classification, the learning speed of GP may become slow due to increasing the number of definition nodes. Therefore, it is difficult to apply the proposed technique to multi-value classification.

For conversion from the association rule into decision trees, we use the following procedures.

1. For the first process, the route of the decision tree is constructed, assuming the conditions of the association rule as the attribute-based tests of the decision tree.
2. In the next process, the conclusions of the association rule is appended on the terminal node of this route.
3. Finally, the class value of the terminal nodes which are not defined by the association rule are assigned by randomly choosing from the terminal nodes set.

In conversion from the association rule to the decision tree, a rule which contains class attribute in the conclusion part is selected. One decision tree is converted based on one association rule. A too simple decision tree is generated by conversion, but the decision tree of high accuracy is not necessary to GP's initial individuals, because of GP learning. The conversion does not make the amount of the calculation increase because it is simple conversion. For conversion from the GP's decision tree to the classification rule, we use the process proposed by Quinlan [73.5].

73.4 Apply to Rule Discovery from Database

We applied the proposed technique for the meningoencephalitis diagnosis data sets. This database was donated by S.Tsumoto[73.6]. We applied the proposed technique for "find factors important for diagnosis (DIAG2) to judge bacteria or virus". We obtained following results of decision tree and rules generated by ADF-GP. In the proposed method, we took the association rule generated by Apriori algorithm as initial individuals of GP. We used 70 data for training, 140 data for test. 70 data was extracted at random. We studied these data by using the normal GP, and tuned of the GP parameter before experiment.

We defined some expressions. “A eq B” is express that attribute(A) is equal to attribute(B) if its attribute is discrete value. “A && B” represents to connect each part(A,B) of rules by “and”. The left side of “→” express conditions of rule, and the right side of “→” express conclusion of rule (or class name).

The section 73.4.1 shows the results using ADF-GP only. The section 73.4.2 shows the results using proposed technique.

73.4.1 ADF-GP Only

The following rules are generated with ADF-GP. The generated rules are composed by the categorical attributes.

```

=== generated rules ===
rule1:
  (EEG_FOCUS eq "-") && (CT_FIND eq "normal") && (SEX eq "M")
  && (RISK eq "n") -> VIRUS
rule2:
  (EEG_FOCUS eq "-") && (CT_FIND eq "normal") && (SEX eq "M")
  && (RISK eq "p") -> BACTERIA
rule3:
  (EEG_FOCUS eq "-") && (CT_FIND eq "normal") && (SEX eq "F")
  && (RISK eq "n") -> VIRUS
rule4:
  (EEG_FOCUS eq "-") && (CT_FIND eq "normal") && (SEX eq "F")
  && (RISK eq "p") -> BACTERIA
rule5:
  (EEG_FOCUS eq "+") && (CT_FIND eq "abnormal") && (SEX eq "F")
  && (RISK eq "n") -> VIRUS
rule6:
  (EEG_FOCUS eq "+") && (CT_FIND eq "abnormal") && (SEX eq "F")
  && (RISK eq "p") -> BACTERIA
rule7:
  (EEG_FOCUS eq "+") && (CT_FIND eq "abnormal") && (SEX eq "M")
  -> BACTERIA
rule8:
  (EEG_FOCUS eq "-") && (CT_FIND eq "abnormal") -> BACTERIA
rule9:
  (EEG_FOCUS eq "+") && (CT_FIND eq "normal") -> VIRUS

```

To examine the availability and the accuracy of the generated rule, the size of the rule, the use frequency and the wrong classification frequency (wrong classification rate) to all data, the classification class by rules are shown in Table(73.1). In the table, the rule 6 is not used for all data. The rules (1 and 3) with high availability show low wrong classification rates. Other rules have high wrong classification rate independent of availability.

To examine the classification accuracy of the generated rule set, each classification distribution to all data are shown in Table(73.2). The table shows that small number of data could not classify VIRUS and BACTERIA correctly.

73.4.2 Proposed Technique (Association Rules + ADF-GP)

The following rules are generated with proposed technique. The generated rules are composed by the continuous value attributes.

Table 73.1. Evaluation on test data by each rules (ADF-GP only)

Rule	Size	Used	Wrong		
1	4	33	4	(12.12 %)	: VIRUS.
2	4	6	2	(33.33 %)	: BACTERIA.
3	4	36	3	(8.33 %)	: VIRUS.
4	4	2	0	(0.00 %)	: BACTERIA.
5	4	7	0	(0.00 %)	: VIRUS.
6	4	0	0	(0.00 %)	: BACTERIA.
7	3	5	1	(20.00 %)	: BACTERIA.
8	2	27	8	(29.63 %)	: BACTERIA.
9	2	24	6	(25.00 %)	: VIRUS.

Table 73.2. Evaluation on test data by error distribution(ADF-GP only)

(a)	(b)	← classified as
87	11	(a):class VIRUS
13	29	(b):class BACTERIA
total hits= 116		

```

=== generated rules ===
rule1:
(Cell_Poly <= 221) -> VIRUS
rule2:
(Cell_Poly > 221) && (EEG_FOCUS <= 200) -> BACTERIA
rule3:
(Cell_Poly > 221) && (EEG_FOCUS > 200) && (GCS <= 121)
-> BACTERIA
rule4:
(Cell_Poly > 221) && (EEG_FOCUS > 200) && (GCS > 121)
&& (SEIZURE == 0) -> VIRUS
rule5:
(Cell_Poly > 221) && (EEG_FOCUS > 200) && (GCS > 121)
&& (SEIZURE != 0) -> BACTERIA

```

The performance of the generated rule are shown in Table(73.3). In the table, the rule 3, 4 and 5 are not used for all data. The rule 1 and 2 have high availability and low wrong classification rates.

Table 73.3. Evaluation on test data by each rules (proposed method)

Rule	Size	Used	Wrong		
1	1	108	10	(9.26 %)	: VIRUS.
2	2	32	0	(0.00 %)	: BACTERIA.
3	3	0	0	(0.00 %)	: BACTERIA.
4	4	0	0	(0.00 %)	: VIRUS.
5	4	0	0	(0.00 %)	: BACTERIA.

To examine the classification accuracy of the generated rule set, each classification distribution to all data is shown in Table(73.4). The table shows that some rules classified BACTERIA as VIRUS by mistake, but almost rules have correct classification ability.

Table 73.4. Evaluation on test data by error distribution (proposed method)

(a)	(b)	← classified as
98	0	(a):class VIRUS
10	32	(b):class BACTERIA
total hits= 130		

73.4.3 Discussion for the Results

In the results, the proposed method shows higher accuracy than ADF-GP, and dataset can be expressed using more small number of rules.

The proposed method does not have pruning rules operation except for GP operations. GP operation is a kind of statistical operation. Thus, sometimes GP operation can obtain interesting rules, but otherwise, the result contains meaningless rules. For such problems, GP technique which contain the pruning operation are proposed [73.7], and it makes possible to build the pruning techniques in our proposed technique. Moreover, it is also possible in the experiment to remove meaningless rules by using the threshold in availability. When the experimental result is evaluated and cleaned by domain expert after experiment, the load for domain expert depends on the number of rules of results. In the proposed technique, the number of rules of results can be reduced compared with only ADF-GP.

We got following comments on these results from domain expert(S. Tsutomu).

Totally, the results obtained by ADF-GP are more interesting than the proposed methods. The results obtained by the proposed technique are very reasonable, but I do not see the meaning of “EEG.FOCUS > 200” and “GCS > 121”. Please let me know what the authors mean by that. Please show me the results for other problems.

The purpose of this research is to achieve high forecast accuracy by small number of rules. This purpose is not as same as expert’s interest on the experiment result. Because expert’s interesting rules were obtained by the normal ADF-GP, expert’s interesting rule can be obtained by the proposed technique by increasing the GP effect.

73.5 Conclusions

In this paper, we proposed the rule discovery technique from the database using genetic programming combined with association rule algorithms. To verify the validity of the proposed method, we applied it to the meningoen- cephalitis diagnosis activity data in a hospital, and discussed the results of proposed method and normal ADF-GP with domain expert. As a result, an improvement of rules’ accuracy was seen, and proposed method can express

dataset by the small number of rules. It can be concluded that the proposed method is an effective method to the improvement of the rules' accuracy and can save the number of rules for the rule discovery problem. Though the comments of domain expert, using only ADF-GP method can be obtained more interesting rules than using proposed method.

In the future, we will research the following 4 topics. The first topic is to apply the method to other verifications. We already applied proposed method for other problems [73.8] [73.9]. We need to discuss the problem suitable for proposed method through the applications to various problems. The second topic is to discuss the conversion algorithm from the association rule to a decision tree with high accuracy. The third topic is to extend the proposed method to multi-value classification problems. It is necessary for this problem to suppress increasing the number of definition nodes and to establish measures against the decrease at the learning speed by increasing nodes. The fourth topic is to obtain more interesting rules such as ADF-GP only.

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74. Medical Knowledge Discovery on the Meningoencephalitis Diagnosis Studied by the Cascade Model

Takashi Okada

Center for Information & Media Studies,
Kwansei Gakuin University
1-1-155 Uegahara, Nishinomiya, Japan

74.1 Introduction

The importance of extracting knowledge from databases is well established in the domain of medical science. Recent advances in hospital automation have introduced databases that store vast amounts of information on patients' case histories. Since experiments involving human patients are not always possible, efficient and flexible data mining is expected to facilitate new medical discoveries from available data.

The objective of this paper was to analyze a meningoencephalitis data set, the test data at the JSAI KDD Challenge 2001 workshop [1], and to help organize the search for new information on this disease. The method of analysis is the cascade model developed by the author. Section 2 briefly introduces the model. The computation procedure for the challenge problem and the resulting rules are shown in Section 3. We also indicate the usefulness of visual inspection of data guided by the obtained rules. The last section discusses possible improvements in data mining using the cascade model.

74.2 The Cascade Model

The model examines an itemset lattice where an [attribute: value] pair is employed as an item to constitute itemsets. Links in the lattice are selected and expressed as rules [2]. Figure 1.1 shows a typical example of a link and its expressed rule. Here, the problem contains five attributes: A–E, each of which takes (y, n) values. The itemset at the upper end of the link has item [A: y], and another item [B: □y] is added along the link. Items of the other attributes are called veiled items. The tables attached to the nodes show the frequencies of veiled items.

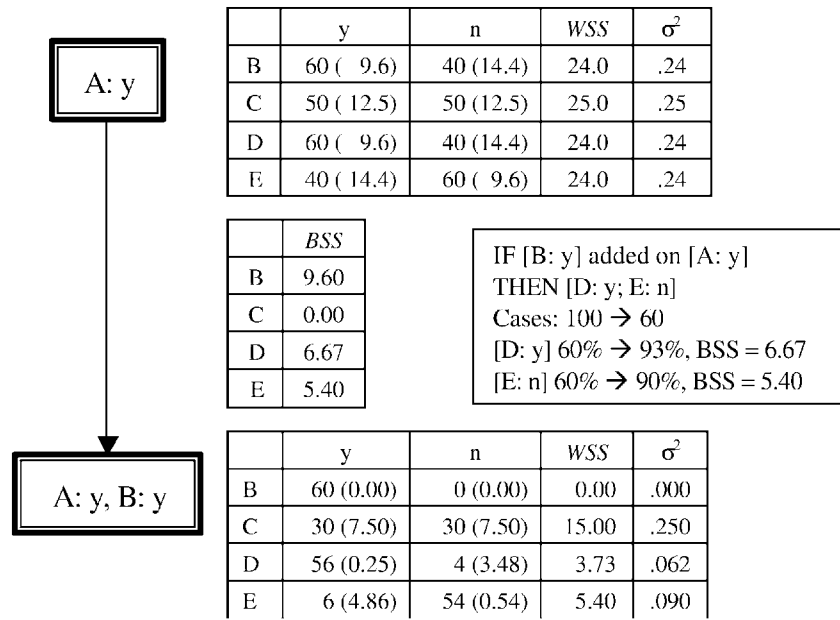


Fig. 1.1. A sample link, its rule expression and properties of the veiled items.

In order to evaluate the strength of a rule, the within-group sum of squares (WSS) and between-group sum of squares (BSS) are defined by the following formulae [3, 4],

$$WSS_i = \frac{n}{2} \left(1 - \sum_a p_i(a)^2 \right) , \tag{1}$$

$$BSS_i = \frac{n^L}{2} \sum_a (p_i^L(a) - p_i^U(a))^2 . \tag{2}$$

where i designates an attribute; the superscripts U and L indicate the upper and lower nodes, respectively; n shows the number of supporting cases of a node; and $p_i(a)$ is the probability of obtaining the value a for attribute i .

Figure 1.1 shows the WSS_i and BSS_i values along with their sample variances. A large BSS_i value is evidence of a strong interaction between the added item and attribute i . The textbox at the right in Figure 1.1 shows the derived rule. The added item [B: y] appears as the main condition in the LHS, while the items in the upper node are placed at the end of the LHS as preconditions. When a veiled attribute has a large BSS_i value, one of its items is placed in the RHS of a rule. The method of selecting items from a veiled attribute was described in [3].

We can control the appearance of attributes in the LHS by restricting the attributes in the itemset node. On the other hand, the attributes in the RHS can be se-

lected by setting the minimum BSS_i value of a rule ($min-BSS_i$) for each attribute. It is not necessary for items in the RHS of a rule to reside in the lattice. This is in sharp contrast to association rule miners, which require the itemset, [A: y; B: y; D: y; E: n] to derive the rule in Figure 1.1. These characteristics of the cascade model make it possible to detect rules efficiently [5].

74.3 Results and Discussion

74.3.1 Computation by DISCAS

The data set provided for the JSAI KDD Challenge 2001 consists of records on 140 meningoencephalitis patients [1]. Each record contains 40 attribute values. All numerical data were categorized as shown in Table 1.1. For example, the attribute “COLD” was converted into one of the three items: “cold \leq 0”, “0<cold \leq 5” or “cold>5”.

We analyzed the data set using DISCAS software (version 2.1), which was developed by the author. Factors affecting diagnosis, detection of bacteria or virus, and prognosis were examined by changing the RHS attribute. The results are shown separately in the following subsections. All calculations were done using a 600-MHz Pentium III PC with 256 MB of memory. The pruning conditions were set to $minsup = 0.01$ and $thres = 0.05$ (see reference [5] for the meaning of these parameters). DISCAS generated a lattice within 2.5 minutes that contained about 50,000 nodes for diagnosis and culture detection problems, while it took 10 minutes of calculation to construct a lattice with 120,000 nodes for the prognosis problem.

We assume that the significance of a rule is roughly proportional to its BSS value, so we show the rules with large BSS values. However, we have to be careful in the selection of rules from computation results, since sets of rules that share many of the same supporting instances should be considered different expressions of the same phenomenon. Let us think of a classification problem for [Class: pos]. If we obtain the following three rules, they show the existence of a data segment sharing items [A: y], [B: n], [C: y], and [Class: pos]. We believe that the strongest rule should be selected from equivalent expressions using the BSS criterion, although other expressions are often useful as related knowledge.

Table 1.1. Categorization of numerical attributes

Attribute	Splitting values
AGE	20, 30, 40, 50
COLD	0, 5
HEADACHE	0, 3, 6, 9
FEVER	0, 3, 6, 10
NAUSEA	0, 3
LOC	0, 1
SEIZURE	0
BT	36, 37, 38, 39
STIFF	0, 1, 2, 3
GCS	14
WBC	5000, 6000, 8000, 10000
CRP	0, 1, 3
ESR	0, 10, 25
CSF_CELL	50, 125, 300, 750
Cell_Poly	8, 20, 50, 300
Cell_Mono	50, 125, 300, 750
CSF_PRO	0, 60, 100, 200
CSF_GLU	40, 50, 60, 70

IF [A: y] added on [B: n] THEN [Class: pos] THEN [C: y]	IF [C: y] added on [B: n] THEN [Class: pos] THEN [A: y]	IF [B: n] added on [A: y] THEN [Class: pos] THEN [C: y]
--	--	--

74.3.2 Diagnosis

The dataset guide indicates that differential diagnosis is important in determining whether the disease is bacterial or viral meningitis. We analyzed the dataset setting DIAG2 (the grouped attribute of DIAG) as the RHS attribute. All attributes were employed as LHS attributes, except DIAG and the 11 attributes whose values were obtained after the initial diagnosis. They were CULTURE, CULT_FIND, THERAPY2, C_COURSE, C_COURSE (Grouped), CSF_CELL3, CSF_CELL7, C_COURSE, COURSE(Grouped), RISK, and RISK(Grouped). The top two rules in the first rule set are shown below. These are the strongest rules leading to the diagnosis of bacterial and viral meningitis, respectively.

```

IF [Cell_Poly > 300] added on []
THEN Diag2 = BACTERIA 30.0% -> 100.0%;

IF [20 < Cell_Poly = 50] added on [CSF_CELL > 750]
THEN Diag2 = VIRUS 38.6% -> 100.0%;

```

Since the cascade model has a search range that is limited in the propositional calculus domain, it cannot draw upon an expert's knowledge in comparing Cell_Poly and Cell_Mono directly. However, we can easily reach the same conclusion if we inspect the scattergram in Fig. 1.2 referencing the constraint: $CSF_CELL = Cell_Poly + Cell_Mono$.

Another analysis is put into practice omitting the attributes: Cell_Poly and Cell_Mono, and the resulting rules are expected to lead to new knowledge, viewed from another point. The rules for which $BSS > 3.0$ are illustrated in Table 1.2.

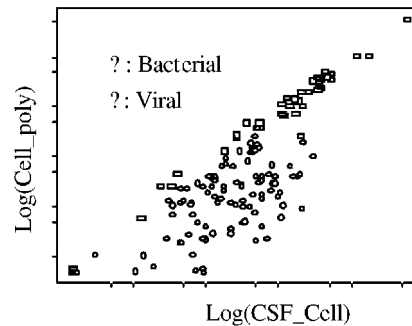


Fig. 1.2. Scatter plot: Cell_poly vs CSF_Cell

Table 1.2. Strong rules obtained for DIAG2

No	Main condition	Preconditions	Change in Diag2 distribution (bacteria virus) †	BSS
1	[CRP>3]	[FOCAL: -]	(27 78) / 105 (15 3) / 18	5.98
	If no precondition is applied, (42 98) / 140 (19 5) / 24, BSS=5.80.			
2	[CT_FIND: abnormal]	[EEG_FOCUS: -]	(32 72) / 105 (19 8) / 27	4.23
	The percentage of [SEX: M] also changes 62% 93%. If no precondition is applied, (42 98) / 140 (23 16) / 39. If [FEVER: 0, EEG_FOCUS: -] is the precondition, (7 17) / 24 (5 0) / 5.			
3	[CT_FIND: abnormal]	[NAUSEA=0, LOC_DAT: -]	(14 37) / 51 (7 0) / 7	3.68

† Values in parentheses show the number of bacterial and viral cases, while the value after the slash gives the number of all instances for all attribute values.

Table 1.3. Strong rules obtained for DIAG

No	Main condition	Preconditions	Changes in Diag distribution (Abscess Bacteria Bacte(E) TB(E) Virus(E) Virus)	BSS
1	[Cell_Poly > 300]	[]	(9 24 8 1 30 68) / 140 → (2 21 7 0 0 0) / 30; Increase in Bacteria, decrease in Virus	8.88
	If [FOCAL: -] is the precondition, (4 19 4 0 14 64) / 105 → (1 16 4 0 0 0) / 21. If [EEG_FOCUS: -] is the precondition, (8 19 4 1 11 61) / 104 → (2 16 4 0 0 0) / 22.			
2	[EEG_FOCUS : +]	[SEX: F, CT_FIND: normal]	(0 6 0 0 13 30) / 49 → (0 1 0 0 10 0) / 11; Increase in Vir(E), decrease in Virus	4.35
	IF [SEX: F] is the precondition, (1 6 0 0 19 32) / 58 → (0 1 0 0 15 2) / 18. IF [CT_FIND: normal] is the precondition, (0 15 4 0 19 63) / 101 → (0 3 3 0 13 5) / 24. IF no precondition is applied, (9 24 8 1 30 68) / 140 → (1 5 4 0 19 7) / 36.			
3	[LOC_DAT: +]	[EEG_FOCUS: -]	(8 19 4 1 11 61) / 104 → (4 8 3 1 8 2) / 26; Decrease in Virus	4.27
4	[CT_FIND: abnormal]	[EEG_FOCUS: -]	(8 19 4 1 11 61) / 104 → (8 7 3 1 5 3) / 27 Decrease in Virus, increase in Abscess	3.95
5	[FOCAL: +]	[CRP≤0, CT_FIND: normal, EEG_FOCUS: -]	(0 3 0 0 5 34) / 42 → (0 1 0 0 5 0) / 6 Decrease in Virus, increase in Virus(E)	3.52
	IF [CRP≤0, EEG_FOCUS: -] is the precondition, (2 5 1 1 8 35) / 52 → (2 2 0 1 7 1) / 13.			
6	[CSF_PRO≤0]	[EEG_FOCUS: -, Cell_Poly ≤ 8]	(5 0 0 0 5 18) / 28 → (5 0 0 0 1 0) / 6; Increase in Abscess, decrease in Virus	2.53
	Major changes in other attributes: [FOCAL = +] 29% → 83%, [CT_FIND: abnormal] 21% → 83%, [CSF_CELL ≤ 50] 39% → 100%, [Cell_Mono ≤ 50] 39% → 100%.			

Figure 1.3 shows the changes in the Diag2 distributions by Spotfire [6]. Axes were selected following Rule 1 in Table 1.2. We can see clear increase in bacteria ratio at the top left pie chart, and the distribution changes in other charts seem reasonable.

Table 1.3 depicts the rules when we employed DIAG as the RHS attribute. The rules for which $BSS > 3.0$ are shown. When no rule appeared to discriminate a class, the strongest rule related to the class was also included, although no rules were found indicating BACTE(E). Six classes appeared in the distribution list, of which the first four were bacterial and the last two were viral. The class showing a remarkable change is underlined. Rules 4 and 6 in Table 1.3 indicate the characteristic segment of an abscess, related to the CT abnormality mentioned in [1].

Pie Chart of Diagnosis

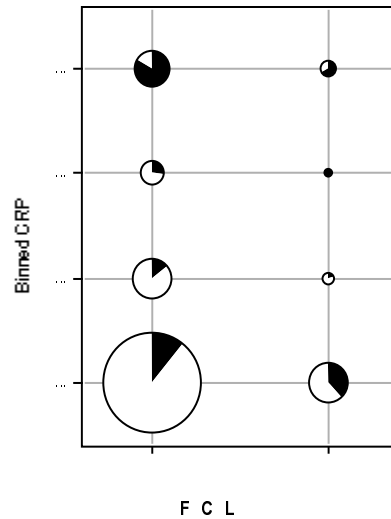


Fig. 1.3. Visualization of Rule 1 in Table 1.2 Black: bacteria; white: virus.

74.3.3 Detection of Bacteria or Virus

Table 1.4 shows the rules with $BSS > 2.0$ when CULT_FIND was used as the RHS attribute. The attributes for the LHS were the same as those in the diagnosis problem. All BSS values are relatively low. In fact, the distribution change shown in Figure 1.4 seems to be unnatural for Rule 1 in Table 1.4. All rules except rule 6 in Table 1.4 deserve no further discussion after such visual inspections are applied. For the problem of specific culture findings, we could detect no strong rules. The only exception was Rule 8 in Table 1.4, with which all species found were herpes.

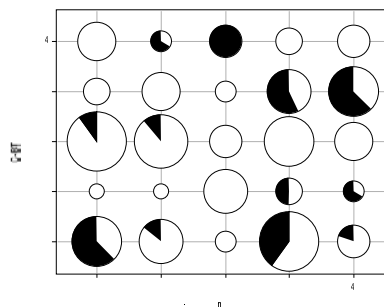


Fig. 1.4. Visualization of Rule 1 in Table 1.4. Black: found; white: not found

Table 1.4. Strong rules obtained for CULT_FIND

No	Main condition	Preconditions	Change in CULT_FIND distribution (False True)	BSS
1	[BT>39.0]	[125<Cell_Mono≤300]	(18 5) / 23 → (0 5) / 5	3.06
2	[38.0<BT≤39.0]	[SEX: M, COLD≤0, 5000<WBC≤6000]	(18 6) / 24 → (0 4) / 4	2.25
	IF [5000<WBC≤6000, CRP≤0] is the precondition, (31 10) / 41 → (2 6) / 8, BSS=2.05.			
3	[HEADACHE≤0]	[FOCAL: −, Cell_Mono≤50]	(14 5) / 19 → (0 4) / 4	2.17
4	[100<CSF_PRO≤200]	[KERNIG: 1]	(25 5) / 30 → (0 4) / 4	2.78
5	[LOC>1]	[SEX: F, COLD≤0]	(27 7) / 34 → (1 5) / 6	2.36
6	[AGE>50]	[SEX: F, CRP≤0]	(24 8) / 32 → (0 4) / 4	2.25
7	[FOCAL: +]	[60<CSF_PRO≤100]	(33 19) / 43 → (1 5) / 6	2.17
	Always accompanied by [CT_FIND: abnormal].			
8	[EEG_FOCUS: +]	[36.0<BT≤37.0]	(14 4) / 18 → (0 3) / 3 All are herpes.	1.81

74.3.4 Prognosis

COURSE(Grouped) was employed as the RHS attribute and the resulting rules with BSS>2.0 are shown in Table 1.5. Only CSF_CELL3 and C_COURSE are omitted from the set of LHS attributes. Even if we use C_COURSE as the RHS attribute, we cannot find a specific course except Rules 3 and 9 in Table 1.5. Rule 3 appears interesting, as it indicates the existence of a data cluster.

Table 1.5. Strong rules obtained for CULT_FIND

No	Main condition	Preconditions	Change in COURSE(Grouped) distribution: (neg pos)	BSS
1	[FOCAL: +]	[Diag2: VIRUS]	(81 17) / 98 → (9 11) / 20	2.84
2	[NAUSEA>3]	[STIFF=2, CULT_FIND: F]	(27 9) / 36 → (0 5) / 5	2.81
3	[THERAPY2: ARA_A]	[SEX: F]	(48 10) / 58 → (0 4) / 4	2.74
	Always accompanied by [DIAG: VIRUS(E), BT≤36.0, LOC_DAT = +, FOCAL = +, EEG_FOCUS = +]. 3 aphasia and 1 amnesia.			
4	[ONSET: SUBACUTE]	[CT_FIND: normal, EEG_FOCUS: −]	(69 8) / 77 → (0 3) / 3	2.41
5	[FOCAL: +]	[Diag2: VIRUS, CRP=0]	(50 12) / 62 → (5 8) / 13	2.31
6	[CSF_GLU>70]	[0<CSF_PRO≤60]	(32 5) / 37 → (0 3) / 3	2.24
7	[NAUSEA>3]	[COLD≤0, LOC_DAT: −, 300<Cell_Mono≤750]	(16 3) / 19 → (0 3) / 3	2.13
8	[LOC>1]	[CULT_FIND: F]	(89 18) / 107 → (2 5) / 7	2.09
9	[CSF_GLU≤40]	[SEX: M, THERAPY2: no_therapy]	(24 5) / 29 → (0 3) / 3 all dead	2.05
10	[FEVER>10]	[40<CSF_GLU≤50]	(26 5) / 31 → (1 4) / 5	2.04
11	[DIAG: VIRUS(E)]	[SEX: F, CULT_FIND: F]	(39 8) / 47 → (5 7) / 12	2.05
12	[100<CSF_PRO≤200]	[STIFF=2]	(37 13) / 50 → (5 9) / 14	2.05

The number of supporting instances for Rule 9 is only 3, but they are all dead. They are shown in the bottom right pie chart in Figure 1.5. If we omit the precondition [Therapy2: no_therapy] during the visual inspection, we can recognize 5 positives (all dead) among 12 patients in the same pie chart.

74.4 Concluding Remarks

The cascade model can provide many strong rules effectively. Sometimes sets of related rules are found by using different *BSS* values and preconditions. We then have to refer them to expert evaluation to determine their importance and validity. Of special interest is whether the *BSS* values are consistent with the importance of the rules.

Although the resulting rules are powerful, several improvements are expected to better express them. The first is the optimization of rules. If we move the split values of categorizations, and add/remove precondition clauses, then the resulting rules will surely be improved. The second is the presentation of related rules. If they are expressed in a group sorted by their *BSS* values, analysis will be easier. The visualization was also proved to be useful if variables in rule conditions are used as axes. Analysts can often detect reasonable/nonsense rules by the visual inspection.

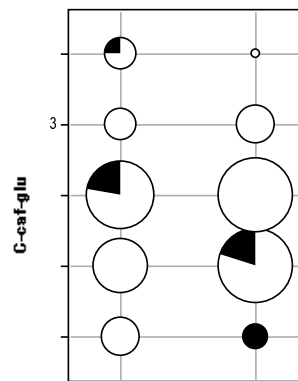


Fig. 1.5. Visualization of Rule 9 in Table 5. Only no_therapy are shown. Black: pos; white: neg.

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75. Meningitis Data Mining by Cooperatively Using GDT-RS and RSBR

Ning Zhong¹, Ju-Zhen Dong¹, and Setsuo Ohsuga²

¹ Dept. of Information Eng., Maebashi Institute of Technology, Japan
zhong@maebashi-it.ac.jp

² Dept. of Information and Computer Science, Waseda University, Japan

This paper describes an application of two rough sets based systems, namely GDT-RS and RSBR respectively, for mining *if-then* rules in a meningitis dataset. GDT-RS (Generalized Distribution Table and Rough Set) is a soft hybrid induction system, and RSBR (Rough Sets with Boolean Reasoning) is used for discretization of real valued attributes as a preprocessing step realized before the GDT-RS starts. We argue that discretization of continuous valued attributes is an important pre-processing step in the rule discovery process. We illustrate the quality of rules discovered by GDT-RS is strongly affected by the result of discretization.

75.1 Introduction

Rough set theory constitutes a sound basis for Knowledge Discovery and Data Mining. It offers useful tools to discover patterns hidden in data in many aspects [75.8, 75.9]. It can be used in different phases of knowledge discovery process such as attribute selection, attribute extraction, data reduction, decision rule generation, and pattern extraction (templates, association rules).

This paper describes an application of two rough sets based systems, namely GDT-RS and RSBR respectively, for mining *if-then* rules in a meningitis dataset. The core of the rule discovery process is GDT-RS that is a soft hybrid induction system for discovering classification rules from databases with uncertainty and incompleteness [75.10, 75.2, 75.3]. The system is based on the combination of *Generalization Distribution Table (GDT)* and the rough set methodology. A GDT is a table in which the probabilistic relationships between concepts and instances over discrete domains are represented. The GDT provides a probabilistic basis for evaluating the strength of a rule. Furthermore, the rough set methodology is used to find minimal relative reducts from the set of rules with larger strengths.

Furthermore, in the pre-processing before using GDT-RS, a system called RSBR is used for discretization of real valued attributes. The system is based on the combination of the rough set method and Boolean reasoning proposed by Nguyen and Skowron [75.6, 75.11]. A variant of the rule selection criteria in GDT-RS is used in RSBR. Thus, the process of the discretization of real valued attributes does not only mean to find the minimal relative reduct, but

also considers the effect of the discretized attribute values on the performance of our induction system GDT-RS.

We argue that discretization of continuous valued attributes is an important pre-processing step in the rule discovery process. Rules induced without discretization are of low quality because they will not recognize many new objects. We illustrate the quality of rules discovered by GDT-RS is strongly affected by the result of discretization.

75.2 Rule Discovery by GDT-RS

GDT-RS is a soft hybrid induction system for discovering classification rules from databases with uncertain and incomplete data [75.10, 75.2]. The system is based on a hybridization of *Generalization Distribution Table (GDT)* and the *Rough Set* methodology. The main features of GDT-RS are the following:

- Biases for search control can be selected in a flexible way. Background knowledge can be used as a bias to control the initiation of GDT and in the rule discovery process.
- The rule discovery process is oriented toward inducing rules with high quality of classification of unseen instances. The rule uncertainty, including the ability to predict unseen instances, can be explicitly represented by the rule strength.
- A minimal set of rules with the minimal (semi-minimal) description length, having large strength, and covering of all instances can be generated.
- Interesting rules can be induced by selecting a discovery target and class transformation.

In [75.10, 75.3], we illustrated the first two features. This paper discusses the last two features of the GDT-RS.

75.2.1 GDT and Rule Strength

Any GDT consists of three components: *possible instances*, *possible generalizations* of instances, and *probabilistic relationships* between possible instances and possible generalizations. Here the *possible instances* are all possible combinations of attribute values in a database; the *possible generalizations* for instances are all possible cases of generalization for all possible instances; the *probabilistic relationships* between possible instances and possible generalizations, represented by entries G_{ij} of a given GDT, are defined by means of a probabilistic distribution describing the strength of the relationship between any possible instance and any possible generalization. The prior distribution is assumed to be uniform, if background knowledge is not available. Thus, it is defined by Eq. (75.1)

$$G_{ij} = p(PI_j|PG_i) = \begin{cases} \frac{1}{N_{PG_i}} & \text{if } PI_j \in PG_i \\ 0 & \text{otherwise} \end{cases} \quad (75.1)$$

where PI_j is the j -th possible instance, PG_i is the i -th possible generalization, and N_{PG_i} is the number of the possible instances satisfying the i -th possible generalization, that is,

$$N_{PG_i} = \prod_{k \in \{l | PG_i[l]=*\}} n_k \quad (75.2)$$

where $PG_i[l]$ is the value of the l -th attribute in the possible generalization PG_i . n_k is the number of different attribute values in attribute k . “*”, which specifies a wild card, denotes the generalization for instances¹. Certainly we have $\sum_j G_{ij} = 1$ for any i .

Let us recall some basic notions for rule discovery from databases represented by decision tables in rough set theory. A decision table is a tuple $T = (U, A, C, D)$, where U is a nonempty finite set of objects called the universe, A is a nonempty finite set of primitive attributes, and $C, D \subseteq A$ are two subsets of attributes that are called condition and decision attributes, respectively [75.8, 75.9]. By $IND(B)$ we denote the indiscernibility relation defined by $B \subseteq A$, $[x]_{IND(B)}$ denotes the indiscernibility (equivalence) class defined by x , and U/B the set of all indiscernibility classes of $IND(B)$.

In our approach, the rules are expressed in the following form:

$$P \rightarrow Q \text{ with } S$$

that is, “if P then Q with the strength S ” where P denotes a conjunction of conditions (i.e. $P \subseteq C$), Q denotes a concept that the rule describes (i.e. $Q \subseteq D$), S is a “measure of strength” of the rule. Furthermore, S consists of three parts: $s(P)$, *accuracy*, and *coverage*, where $s(P)$ is the strength of the generalization P (i.e. the condition of the rule), the *accuracy* of the rule is measured by a noise rate function: $r(P \rightarrow Q)$, *coverage* denotes how many instances are covered by the rule. If some instances covered by the rule also belong to another class, the *coverage* is a set: {number of instances belonging to the class, number of instances belonging to another class}.

The strength of a given rule reflects the incompleteness and uncertainty in the process of rule inducing influenced both by unseen instances and noise. The strength of the generalization $P = PG$ is given by Eq. (75.3) under that assumption that the prior distribution is uniform

$$s(P) = \sum_l p(PI_l|P) = \text{card}([x]_{IND(P)}) \times \frac{1}{N_P} \quad (75.3)$$

where $\text{card}([x]_{IND(P)})$ is the number of observed instances satisfying the generalization P . The strength of the generalization P represents explicitly

¹ For simplicity, we would like to omit the wild card in some places in this paper.

the prediction for unseen instances since possible instances are considered. On the other hand, the noise rate is given by Eq. (75.4)

$$r(P \rightarrow Q) = \frac{\text{card}([x]_{IND(P)} \cap [x]_{IND(Q)})}{\text{card}([x]_{IND(P)})} \tag{75.4}$$

where $\text{card}([x]_{IND(Q)})$ is the number of all instances from the class Q within the instances satisfying the generalization P . It shows the quality of classification measured by the number of instances satisfying the generalization P which cannot be classified into class Q . The user can specify an allowed noise level as a threshold value. Thus, the rule candidates with the larger noise level than a given threshold value will be deleted.

75.2.2 A Searching Algorithm for Optimal Set of Rules

We now describe an idea of a searching algorithm for a set of rules developed in [75.2]. We use a sample database shown in Table 75.1 to illustrate the idea. Let T_{noise} be a threshold value.

Table 75.1. A sample database

$U \backslash A$	a	b	c	d
u1	a_0	b_0	c_1	y
u2	a_0	b_1	c_1	y
u3	a_0	b_0	c_1	y
u4	a_1	b_1	c_0	n
u5	a_0	b_0	c_1	n
u6	a_0	b_2	c_1	n
u7	a_1	b_1	c_1	y

Step 1. Create one or more GDTs.

If prior background knowledge is not available the prior distribution of a generalization is calculated using Eq. (75.1) and Eq. (75.2).

Step 2. Consider the indiscernibility classes with respect to the condition attribute set C (such as u_1, u_3 , and u_5 in the sample database of Table 75.1) as one instance, called a *compound instance* (such as $u'_1 = [u_1]_{IND(a,b,c)}$ in the following table). Then the probabilities of generalizations can be calculated correctly.

$U \backslash A$	a	b	c	d
$u'_1, (u_1, u_3, u_5)$	a_0	b_0	c_1	y,y,n
u_2	a_0	b_1	c_1	y
u_4	a_1	b_1	c_0	n
u_6	a_0	b_2	c_1	n
u_7	a_1	b_1	c_1	y

Step 3. For any compound instance u' (such as the instance u'_1 in the above table), let $d(u')$ be the set of the decision classes to which the instances in u' belong. Furthermore, let $X_v = \{x \in U : d(x) = v\}$ be the decision class corresponding to the decision value v . The rate r_v can be calculated by Eq. (75.4). If there exist a $v \in d(u')$ such that $r_v(u') = \min\{r_{v'}(u') | v' \in d(u')\} < T_{noise}$ then we let the compound instance u' to point to the decision class corresponding to v . If does not exist any $v \in d(u')$ such that $r_v(u') < T_{noise}$, we treat the compound instance u' as a contradictory one, and set the decision class of u' to $\perp(uncertain)$. For example,

	A				
U		a	b	c	d
$u'_1(u_1, u_3, u_5)$		a_0	b_0	c_1	\perp

Let U' be the set of all the instances except the contradictory ones.

Step 4. Select one instance u from U' . Using the idea of discernibility matrix, create a discernibility vector (that is, the row or the column with respect to u in the discernibility matrix) for u . For example, the discernibility vector for instance $u_2 : a_0b_1c_1$ is as follows:

U	$u'_1(\perp)$	$u_2(y)$	$u_4(n)$	$u_6(n)$	$u_7(y)$
$u_2(y)$	b	\emptyset	a, c	b	\emptyset

Step 5. Compute all the so called local relative reducts for the instance u by using the discernibility function. For example, from instance $u_2:a_0b_1c_1$, we obtain two reducts $\{a, b\}$ and $\{b, c\}$:

$$f_T(u_2) = (b) \wedge \top \wedge (a \vee c) \wedge (b) \wedge \top = (a \wedge b) \vee (b \wedge c).$$

Step 6. Construct rules from the local reducts for the instance u , and revise the strength of each rule using Eqs. (75.3) and (75.4). For example, the following rules are acquired

$$\{a_0b_1\} \rightarrow y \text{ with } S = 1 \times \frac{1}{2} = 0.5, \text{ and}$$

$$\{b_1c_1\} \rightarrow y \text{ with } S = 2 \times \frac{1}{2} = 1 \text{ for the instance } u_2:a_0b_1c_1.$$

Step 7. Select the best rules from the rules (for u) obtained in *Step 6* according to its priority [75.10]. For example, the rule “ $\{b_1c_1\} \rightarrow y$ ” is selected for the instance $u_2:a_0b_1c_1$ because it matches more instances than the rule “ $\{a_0b_1\} \rightarrow y$ ”.

Step 8. $U' = U' - \{u\}$. If $U' \neq \emptyset$, then go back to *Step 4*. Otherwise, go to *Step 9*.

Step 9. If any rule selected in *Step 7* is covering exactly one instance then STOP, otherwise, select a minimal set of rules covering all instances in the decision table.

The following table shows the result for the sample database shown in Table 75.1.

U	rules	s(P)	accuracy	coverage
u_1, u_3, u_5	$b_0 \rightarrow y$	0.25	0.67	{2, 1}
u_2, u_7	$b_1 \wedge c_1 \rightarrow y$	1	1	2
u_4	$c_0 \rightarrow n$	0.17	1	1
u_6	$b_2 \rightarrow n$	0.25	1	1

One can see that the discovered rule set is a minimal one having large strength and covering of all instances. Furthermore, the searching algorithm can be conveniently used to discover a rule set with respect to an interesting class (or a subset of classes) selected by the user as a discovery target. Thus, by using class selection/transformation, and combining with the some pre-processing steps such as discretization, we can obtain more interesting results.

75.3 Discretization Based on RSBR

Discretization of continuous valued attributes is an important pre-processing step in the process for rule discovery in the databases with mixed type of data including continuous valued attributes. In order to solve the discretization issues, we have developed a discretization system called RSBR that is based on hybridization of rough sets and Boolean reasoning proposed in [75.6].

A great effort has been made (see e.g. [75.5, 75.1, 75.4, 75.7]) to find effective methods for discretization of continuous valued attributes. We may obtain different results by using different discretization methods. The results of discretization affect directly the quality of the discovered rules. Some of discretization methods totally ignore the effect of the discretized attribute values on the performance of the induction algorithm. RSBR combines discretization of continuous valued attributes and classification together. In the process of the discretization of continuous valued attributes we should also take into account the effect of the discretization on the performance of our induction system GDT-RS.

Roughly speaking, the basic concepts of the discretization based on RSBR can be summarized as follows:

- Discretization of a decision table $T = (U, A \cup \{d\})$, where $V_a = [v_a, w_a)$ is an interval of real values taken by attribute a is a searching process for a partition P_a of V_a for any $a \in A$ satisfying some optimization criteria (like minimal partition) preserving some discernibility constraints [75.6].
- Any partition of V_a is defined by a sequence of the so-called *cuts* $v_1 < v_2 < \dots < v_k$ from V_a .
- Any family of partitions $\{P_a\}_{a \in A}$ can be identified with a set of cuts.

75.4 Application in Meningitis Data Mining

This section shows the results of mining in a meningitis dataset by using cooperatively GDT-RS and RSBR.

In the meningitis dataset, 19 of 38 attributes are continuous valued attributes that must be discretized by RSBR before rule induction by GDT-RS. Since the quality of rules discovered by GDT-RS is strongly affected by the result of discretization of continuous valued attributes, we need to do the discretization of continuous valued attributes carefully.

Furthermore, in this experiment, for each decision attribute with multi-class, we used two different modes of cooperatively using GDT-RS and RSBR:

1. All classes in a decision attribute are considered simultaneously when using RSBR for discretization.
2. Focus on an interesting class selected by a user as positive class (+) and other classes are considered as negative class (-). The GDT-RS and RSBR are cooperatively used to find the rules with respect to the focused positive class. After that, a class with respect to negative class is selected as a new interesting positive class, and then the RSBR and GDT-RS are cooperatively used again. Repeat this process until all interesting classes are selected as positive class.

Here we show an interesting result. That is, finding factors important for predicting prognosis (COURSE and C_COURSE).

First we consider all classes when discretization. The following 2 of 11 reasonable rules are interesting ones.

$$r_{1.1} : FEVER(\geq 8) \wedge BT(< 37.1) \rightarrow CULTURE(-)$$

with coverage = {13, 2}, accuracy = 86%.

$$r_{1.2} : FOCAL(+) \wedge CT_FIND(normal) \rightarrow CULTURE(-)$$

with coverage = {12, 2}, accuracy = 85%.

Then we focus on an interesting class, that is, CULTURE(-). The following 2 of 26 reasonable rules are interesting ones.

$$r_{2.1} : COLD(< 9) \wedge BT(\geq 37.1) \wedge LOC_DAT(-) \wedge Cell_Mono(< 429)$$

$\rightarrow CULTURE(-)$ with coverage = 31, accuracy = 1.

$$r_{2.2} : COLD(< 9) \wedge LOC_DAT(-) \wedge Cell_Poly(\geq 32) \wedge CSF_PRO(< 93)$$

$\rightarrow CULTURE(-)$ with coverage = 30, accuracy = 1.

According to a medical doctor opinion, all these rules ($r_{1.1}, r_{1.2}$ and $r_{2.1}, r_{2.2}$) are reasonable, but the rules, $r_{2.1}, r_{2.2}$, which are learned by focusing on an interesting class, are much better ones.

This example shows that more interesting rules can be generated by selecting an interesting discovery target because the better result of discretization is obtained.

75.5 Conclusion

We have presented an application of two rough sets based systems, GDT-RS and RSBR, for mining *if-then* rules from a meningitis dataset. The experimental results illustrate that the quality of rules discovered by GDT-RS is

strongly affected by the results of discretization of continuous valued attributes. We need to do the discretization of continuous valued attributes carefully. Using cooperatively RSB and GDT-RS is a good way for rule discovery in the datasets with mixed type of attributes and multi-class.

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