Agent-Based Social Systems 12

Setsuya Kurahashi · Hiroshi Takahashi
Editors

Innovative Approaches in Agent-Based Modelling and Business Intelligence

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Agent-Based Social Systems

Volume 12

This series is intended to further the creation of the science of agent-based social systems, a field that is establishing itself as a transdisciplinary and cross-cultural science. The series will cover a broad spectrum of sciences, such as social systems theory, sociology, business administration, management information science, organization science, computational mathematical organization theory, economics, evolutionary economics, international political science, jurisprudence, policy science, socioinformation studies, cognitive science, artificial intelligence, complex adaptive systems theory, philosophy of science, and other related disciplines.

The series will provide a systematic study of the various new cross-cultural arenas of the human sciences. Such an approach has been successfully tried several times in the history of the modern science of humanities and systems and has helped to create such important conceptual frameworks and theories as cybernetics, synergetics, general systems theory, cognitive science, and complex adaptive systems.

We want to create a conceptual framework and design theory for socioeconomic systems of the twenty-first century in a cross-cultural and transdisciplinary context. For this purpose we plan to take an agent-based approach. Developed over the last decade, agent-based modeling is a new trend within the social sciences and is a child of the modern sciences of humanities and systems. In this series the term "agent-based" is used across a broad spectrum that includes not only the classical usage of the normative and rational agent but also an interpretive and subjective agent. We seek the antinomy of the macro and micro, subjective and rational, functional and structural, bottom-up and top-down, global and local, and structure and agency within the social sciences. Agent-based modeling includes both sides of these opposites. "Agent" is our grounding for modeling; simulation, theory, and realworld grounding are also required.

As an approach, agent-based simulation is an important tool for the new experimental fields of the social sciences; it can be used to provide explanations and decision support for real-world problems, and its theories include both conceptual and mathematical ones. A conceptual approach is vital for creating new frameworks of the worldview, and the mathematical approach is essential to clarify the logical structure of any new framework or model. Exploration of several different ways of real-world grounding is required for this approach. Other issues to be considered in the series include the systems design of this century's global and local socioeconomic systems.

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Preface

The purpose of this book is to thoroughly prepare the reader at an intermediate level for research in social science, organization studies, economics, finance, marketing science, and business science as complex adaptive systems. Those who are not familiar with a computational research approach may see the advantages of social simulation studies and business intelligence, and experienced modelers may also find various instructive examples using agent-based modeling and business intelligence approaches to inspire their own work. In addition, the book discusses cutting-edge techniques for complex adaptive systems through their applications.

Business science studies so far have focused only on data science and analyses of business problems. However, these studies to enhance the capabilities of conventional techniques in the fields have not been investigated adequately. The emphasis in this book is managing the issues of societies, firms, and organizations for achieving profit on interaction with agent-based modeling, human- and computer-mixed systems, and business intelligence approaches, as such a focus is also fundamental for complex but bounded rational business environments.

Appropriate for a diverse readership, there are multiple ways to read this book depending on readers' interests in the areas of application and on their level of technical skills. Researchers familiar with fields such as social science and business science studies may compare the ideas expressed here using simulation models with empirical studies.

Innovative Approaches in Agent-Based Modelling and Business Intelligence encourages readers inspired by intensive research works by leading authors in the field to join with other disciplines and extend the scope of the book with their own unique contributions. Agent-based modeling and business intelligence with the latest results in this book allow readers who are researchers, students, and professionals to resolve their problems through the common challenges posed by computational social and business science researchers involved in both areas in order to create a valuable synergy.

This book contains 19 chapters. The following are their synopses. Takao Terano discusses the basic principles and key ideas of EBMS which is a just started new field of both scientific and practical activities in his Chap. 1.

Kotaro Ohori and Hirokazu Anai present a novel research project, which they call "social mathematics," to resolve social issues based on mathematical and artificial intelligence technologies in their Chap. 2.

Chathura Rajapakse, Lakshika Amarasinghe, and Kushan Ratnayake present the details of an agent-based simulation model developed to study the impact of seepage behavior, which means the smaller vehicles moving forward through the gaps between larger vehicles without following the lanes in the traffic congestion in their Chap. 3.

Hiroshi Takahashi discusses the influence of information technology on business and finance. He also looks to offer an overview of the kind of research agent-based models are enabling in his Chap. 4.

Takashi Ishikawa investigates the mechanism of coevolving networks using a generalized adaptive voter model based on related work and the homophily principle which is known as a driving mechanism to form community structure in social networks in his Chap. 5.

Yoko Ishino proposes a new method for obtaining an appropriate structure for a Bayesian network by using sensitivity analysis in a stepwise fashion in her Chap. 6.

Hiroaki Jotaki, Yasuo Yamashita, Satoru Takahashi, and Hiroshi Takahashi analyzes the influence of text information on credit markets in Japan in their Chap. 7. It focuses on headline news, a source of information that has immediate influence on the money market and also which is regarded as an important source of information when making investment decisions.

Yasuo Kadono tries to develop an integrated approach of data obtained from issue-oriented large-scale fact-finding surveys, statistical analyses based on dynamic modeling, and simulations in his Chap. 8.

Hajime Kita shows the experience of 20-year study of the artificial market and discusses its future in his Chap. 9.

Masaaki Kunigami introduces a new formulation called the Doubly Structural Network (DSN) Model and shows its applications in socioeconomics and education in his Chap. 10.

Setsuya Kurahashi looks back at the history of science in order to introduce one method so that ABS can develop to more reliable social science in his Chap. 11. It also overviews the validity of modeling, ABM as an inductive inference and deductive inference.

Zhenxi Chen and Thomas Lux apply the simulated method of moment estimator proposed by Chen and Lux to investigate the herding behavior in the Chinese stock market using high-frequency data in their Chap. 12.

Akira Ota, Gadea Uriel, Hiroshi Takahashi, and Toshiyuki Kaneda discuss factors of the pedestrian flows in two different underground malls by conducting multiple regression analysis with visibility measures based on space syntax theory and store proximity measures in their Chap. 13.

Makoto Sonohara, Kohei Sakai, Masakazu Takahshi, and Toshiyuki Kaneda focus on tourists' evacuation behavior who don't have enough knowledge of evacuation sites and routes in their Chap. 14. Their study shows an agent modeling technique using a sampling survey of the web-based questionnaire considering the information behaviors and the earthquake experiences and a tourist evacuation agent model using this technique.

Shingo Takahashi proposes "virtual grounding" as a grounding method for constructing valid facsimile models where real data for behavioral model parameter identification are not available in his Chap. 15.

Toru B. Takahashi proposes a problem-solving support agent that interactively supports human problem solving activities in his Chap. 16. Prior to the development of the problem-solving support agent, he organized the problem solving process and researched the types of mistakes involved in the process.

Wander Jager, Geeske Scholz, Reńe Mellema, and Setsuya Kurahashi discuss their experiences with the Energy Transition Game (ETG) in Groningen, Tokyo, and Osnabrück, all in educational settings in their Chap. 17. The ETG is an agent-based game in which roles that can be played are energy companies and political parties. A unique aspect is the inclusion of an artificial population of simulated people.

Chao Yang proposes a co-evolutionary opinion model of the social network based on bounded confidence, reference range, and interactive influence in her Chap. 18.

Finally, Takashi Yamada reviews the activities of Prof. Dr Takao Terano's laboratory at Tokyo Institute of Technology and briefly introduces several representative papers especially in social simulation literature in his Chap. 19.

Acknowledgements As the editors, we would like to thank Prof. Takao Terano. He has been a leading researcher in agent-based modeling fields for several decades. Finally, we wish to express our gratitude to all the authors.

Tokyo, Japan — Setsuya Kurahashi
Yokohama, Japan — Hiroshi Takahashi
June 2018

Contents

Chapter 1
Gallery for Evolutionary Computation and Artificial Intelligence Researches: Where Do We Come from and Where Shall We Go

Takao Terano

Abstract D'où venons-nous? Que sommes-nous? Où allons-nous? (Where do we come from? What are we? Where are we going?) is the title of a famous painting by Paul Gauguin created in his Tahiti days. The title raises very important but hard questions of our life. Contrary to the heavy questions, I started GEAR research group in 1990 in a very easy way, when he moved from a computer system engineer to a professor of Graduate School of Systems Management at Tsukuba University. Since then, as described in this book in total, we are concerning on the research and development for evolutionary computation and artificial intelligence researches. The name GEAR comes from the acronym. This short paper describes the history of experimental methods in social and management sciences referring to our experience and discusses the importance of agent-based approaches as interdisciplinary and integrated fields on complex systems. Yes, I and my colleagues are also facing with very heavy questions: Can we or should we simulate them? Where are agent-based approaches going? The paper concludes with the statements on where shall we go in the complex world in the near future.

Keywords Evolutionary computation · Artificial intelligence · Agent-based approaches · Management science

1.1 The Shape of Jazz to Come: Introduction

Ornette Coleman, a jazz alto sax player, started "free jazz" activities in the end of 1950s. On those days, they thought that Ornette played only nonsense without any jazz theories and that audiences could not welcome the music. However, the jazz

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history says Ornette was an excellent player, who was able to vividly play Charlie Parker's adlib music as if he was alive. Also, his activities have gradually become popular in the jazz literature (Segell 2005).

Same as the history of jazz, it is often the case that they could not understand the essential meanings in some scientific researches such as physics or mathematics: the birth of quantum mechanics, non-Euclidean geometry, and recent econo-physics are typical examples of such fields. First, they usually think bland new theories and nonsense ideas; they neglect them, and then, however, they gradually accept new ones because of the appearance of new evidences. I believe that experiment-based approaches in management and social sciences (EBMS) should follow such traditions of new scientific and practical activities. In this short article, I would like to draw the shape of EBMS to come referring to the titles of (fairly) popular (jazz) music.

1.2 A Child Is Born: When Experimental Methods Started

"A Child is Born" is composed and played by Thad Jones, a jazz trumpeter.

In the literature, the experimental approach to management or social sciences started from the pioneering work of Cyert and March in the 1960s (Cyert and March 1963). Also, the garbage can model by Cohen et al. (1972) is well-known. The existence of such early works is very remarkable, as both Fortran and Lisp, traditional programming languages for numerical and symbolic computation, were developed in 1960. However, because of the limits of computer performance and the immaturity of programming techniques, for researchers in noncomputer science-related fields, especially social scientists, the approach has not been successful in those days.

The second leap of EBMS was found in the early 1990s. In those days, researchers in distributed artificial intelligence fields have become interested in agent-based approaches. Agent-based modeling (ABM) or agent-based simulation (ABS) was a new modeling paradigm in those days (Axelrod 1994; Epstein 2006). It focuses from global phenomena to individuals in the model and tries to observe how individuals with individual characteristics or "agents" will behave as a group. The strength of ABM/ABS is that it stands between the case studies and mathematical models. It enables us to validate social theories by executing programs, along with description of the subject and strict theoretical development.

Interestingly, the movement of agent-based approach to social simulation or experimental management science spontaneously emerged worldwide (Terano 2007). In European region, they started SIMSOC (SIMulating SOCiety) meetings, which are followed by the activities of ESSA (European Social Simulation Association) and JASSS (J. Artificial Societies and Social Simulation). In the North American region, COT (Computational Organization Theory) workshops were started at AAAI and Informs Conferences, and then CASOS (Computational Analysis of Social and Organizational Systems), *CMOT (Computational and*

Mathematical Organization Theory) Journal, NAACSOS (North American Association for Computational Social and Organization Sciences), and then CSSSA (Computational Social Science Society of the Americas) activities followed.

In Japan, we organized PATRA (Poly-Agent Theory and ReseArch) group and then continue to have the series of AESCS (Agent-Based Approaches in Economic and Social Complex Systems) workshops hosted by PAAA (Pacific-Asian Association for Agent-based Approach in Social Systems Sciences).

In summary, therefore, we have already had a long history on EMBS.

1.3 Now or Never: Why Not Now

"Now or Never" is composed and played by Hiromi Uehara, a jazz pianist.

Now, we must develop, extend, and then establish EBMS research in front of a large number of audiences because of the following two reasons:

1. Recent rapid progress of computer and network technologies makes us possible to easily implement computer-based simulation models. Such models help us to carry out EBMS with both machine agents and human subjects. Also, using such models, we are able to operationalize the concepts and ways of thinking of traditional management sciences. By the word operationalize, we mean that (i) social and organizational systems are observed by human experiments and computer simulations, and (ii) with both machine- and human-readable documentations, they are comprehensively and consistently understood for human experts and students related to management sciences.
2. Because of the recent crises of economic conditions worldwide and the tragedy of the great earthquake in Japan, we must deeply understand the mechanisms of human societies. We must develop the new principles of design and implementation of societies. Contrary to physical sciences domains, there are no first principles in management science domains. Therefore, the experimental approach is indispensable to uncover the secrets of human societies.

1.4 Pick Up the Pieces: What Are Elements

"Pick up the Pieces" is mainly played by the Candy Dulfer's fusion music group. She is both a singer and a sax player.

To build a new EMBS architecture, we have already had various pieces or tools and techniques in our laboratory. Some of them are listed in the other papers in this book. The most important ideas of agent-based modeling in EBMS are first, in agent-based modeling, micro-macro links between agent interactions and environmental conditions shown in Fig. 1.1, and second, the architecture to uncover the interactions of micro-, mezzo-, and macroscopic levels among agents shown in Fig. 1.2.

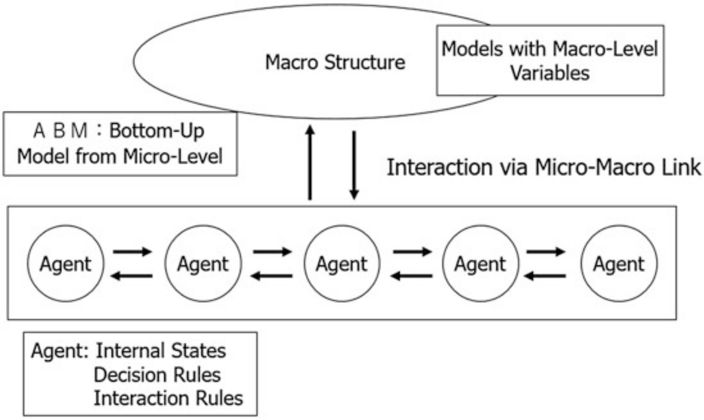
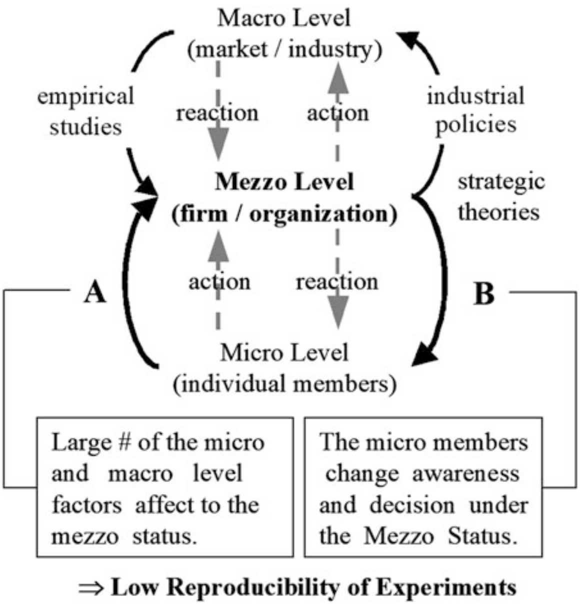


Fig. 1.1 Principle of agent-based modeling

Fig. 1.2 Structures and formulation of management problems



In Fig. 1.1, an agent mean a model of human, firm, or objects, as a software component, which is equipped with internal states, decision rules, and information exchange mechanisms. As results of microlevel interactions of agents, macro level observable phenomena emerge. Furthermore, as each agent is able to observe such macro level phenomena, it might change its decisions and behaviors. Then complex micro-macro links among them may occur. The phenomena are observed in economic behaviors, social network behaviors, and group decisions in recent complex real-world problems. In ABM/ABS, behaviors and statuses of individual agents are coded into programs by researchers. They also implement information and analytical systems in the environment, so the model itself may be very simple. Even when the number or variety of agents increases, the complexity of simulation descriptions itself will not increase very much. (Axelrod 1997) has emphasizes that the goal of agent-based modeling is to enrich our understanding of fundamental processes that may appear in a variety of applications.

In Fig. 1.2, we introduce a mezzo-scopic structure between the microscopic (members/customers) and the macroscopic (market/industry) level. The problems on the business processes and organizational administration have such difficulties as (a) the problems have complexity with numerous factors in hierarchical structures, and (b) each structural behavior strongly depends on the member's awareness and decisions. Such complex systems have been often described from the micro-macro loop viewpoint, because the business/organizational problems exist in the mezzo-scopic level in which they have no enough scale differences to neglect their uniqueness nor heterogeneity of their customers/employees in the firm. On the other hand, although recent researches on service sciences and/or the econo-physics adopt the outcomes from experimental economics or behavioral economics, they tend to only explain macro level phenomena from the microlevel customers or investors as the homogeneous set of agents or particles.

Figure 1.2 also illustrates these difficulties from the viewpoints of the interactions between micro-, mezzo-, and macroscopic levels. Arrow "A" indicates that the microlevel (members/customers) numerous factors affect the mezzo-level (corporation/organization) states. Arrow "B" shows the mezzo-level influence on the microlevel actors' awareness and decisions.

Introducing both the diversity of microlevel agent's awareness/decisions without off-scaling and an intermediate level structure enables to explore the emergence of organizational deviation and kaizen in corporation management. Actual business and administrative processes include both "A" and "B" inter-level interactions. The existence of these two interaction levels bring the low reproducibility of the business problem, we mentioned ahead that single experiment is not effective to explore the problems. Therefore, we need to apply appropriate experiment-based approaches to each "A" and "B." We believe that, at first, we present the bottom-up simulation with the orthogonal design of experiments as the approach for "A" and that, then next, the combination methodology of gaming/narrative approach and the orthogonal design is also presented for "B."

Our current pieces for EBMS include (i) agent-based simulation techniques to explore vast parameter spaces with evolutionary algorithms and grid computers (Yang et al. 2012), (ii) the combination of the organizational bottom-up simulations and the orthogonal designs of experiments, (iii) a new experimental method to measure the awareness via the integration of business games and the manga/narrative business cases, (iv) visualizing techniques for human decisions and behaviors of business processes, (v) conjoint analysis techniques with personae and/or organizational profiles, (vi) abstraction techniques of the agents' semantic networks, and (vii) virtual scenarios and case set generation techniques based on the concept of design of experiments. About the detailed explanations on these pieces, please refer to the papers elsewhere.

1.5 Place to Be: Where Should We Focus On

"Place to be" is composed and played by Hiromi Uehara, a jazz pianist.

Using the pieces, we are attacking several critical problems on social, organizational, and/or economic fields. The recent lists are found in our GEAR website (GEAR 2018). They are categorized into the following items:

1. Research and development of advanced knowledge systems, which include data mining, marketing, education, social networking, recommendation, and manufacturing task domain problems
2. Application of agent-based social system sciences, which include organization, business, history, education, and financial task domains
3. Integration of gaming and case methods, which include marketing, business competition, finance, manga cases, human/computer participating gaming task domains
4. Theories for EBMS, which include double-structured networks, chaos controls, behavioral finances, and games

As found in information in GEAR website, we have already published over 1000 articles in both English and Japanese languages with about 320 coauthors. The network structure of the coauthor network is shown in Fig. 1.3, which shows, of course, the scale-free property in complex network theory.

These task domains are on the boundaries of traditional academic fields such as economics, organizational sciences, statistical physics, operations research, artificial intelligence, computer science, and system science. To address EBMS, we must focus not only on the principled approaches of traditional experimental methods discussed elsewhere but also agent technologies, which are characterized by their internal states, problem-solving and decision-making functionalities, and interaction capabilities.

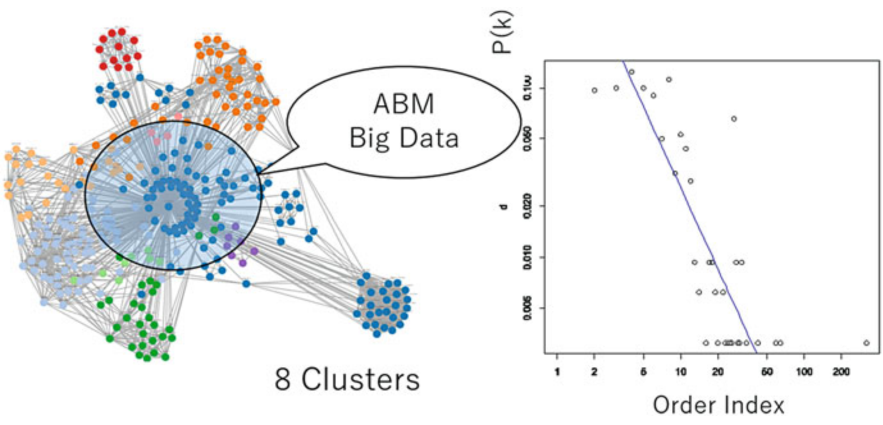


Fig. 1.3 Coauthor network of articles in GEAR research group in 2018

1.6 Act Your Age: Which Way to Go

"Act Your Age" is composed and played by Gordon Goodwin with his Big Phat Band. He is a jazz pianist and a sax player.

To act our age in EBMS fields properly, I would like to emphasize the following three points:

1. Architecture (Hamano 2008) and code (Lessig 2006): The term architecture usually means a building, a typical artificial object. However, some of artificial systems we have built often show emergent properties. The Internet and social network sites are typical examples. In these artificial systems, they often become autonomous and out of control. The term code means such implicit rules determined by laws, cultures, and customs. They determine our both conscious and unconscious behaviors and/or beliefs. The concepts of architecture and code are critical to develop EBMS, because our experiments in social systems are deeply affected by the concepts.
2. Control and harness (Axelrod and Cohen 2000): About complex adaptive systems, the book states that they are not controllable and they should be harnessed. By harness, they mean to deal with things by natural forces; thus, compared with control, harness is a very calm concept. To harness (social and organizational) systems, Axelrod and Cohen emphasize the principle of evolution of life: copying, recombination, and selection. Their statements are very conformable to EBMS, because our experimental strategies heavily depend on evolutionary computation techniques.
3. Body points for acupuncture and moxibustion in oriental medicine: In oriental medicine, acupuncture points are important concepts to transfer therapy knowledge to others. Without the concepts, they are hard to make therapies of acupuncture and moxibustion, because the treatment itself requires very tacit knowledge and experience. They say the concepts of body points were invented once upon a time. To make clear the name and place of body points, the treatment techniques are considered to be distributed. Our pieces of EBMS have similar properties. Using our pieces, we are able to translate and transmit the results of EBMS with clear explanations to ordinary people in every field.

1.7 Adios Nonino: Concluding Remarks

"Adios Nonino" is composed and played by Astor Piazzolla, a Latin musician. The tune was composed, when the father of Astor passed away in order to pray for his death. The tune is, however, very beautiful with little feeling of the sadness on his death.

In this short paper, I have discussed the basic principles and key ideas of EBMS. EBMS is a just started new field of both scientific and practical activities. I believe, however, EBMS will be a major field in the near future to deal with real-world problems in our societies. Interestingly, Segell emphasizes the importance of the network of herds in a new community in the music world in his book (Segell 2005). To make progress in EBMS, I would like to ask a favor for your participation with your herds.

As take-home bring message, I would like to conclude the paper in the following statements:

– Agent simulation is a lie that helps us see reality
  (Original: Art is a lie that helps us see reality by Pablo Picasso).
– Something may be obvious once you know agent simulation
  (Original: Everything is obvious once you know the answers from the book title of Duncan J. Watts).

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Chapter 2
Mathematical Technologies and Artificial Intelligence Toward Human-Centric Innovation

Kotaro Ohori and Hirokazu Anai

Abstract This paper presents a novel research project, which we call "social mathematics," to resolve social issues (including complex and uncertain human activities) based on mathematical and artificial intelligence technologies. The research project aims to build the techniques for social system modeling, policy design and evaluation, and then to create a methodology of design processes for social systems. To clarify the elements of the techniques and methodology, we have tackled various types of case studies for resolving social issues. Through the case studies, we confirmed that the communication between the researchers and stakeholders is important in order to eliminate the discrepancy of cognition about problem situations. On the other hand, there were unique difficulties that we could not resolve easily in the system design processes. The future direction of this study is to systematize the important elements for social system design by analyzing the difficulties in detail while increasing case studies in different situations.

Keywords Social system design · Mathematical technologies · Artificial intelligence

2.1 Introduction

In recent years, governments and business enterprises have focused on addressing social issues including complex and uncertain human activities in various types of social systems. Fujitsu Laboratories Limited launched a research project in 2010 to realize an "Intelligent Society (Hara and Ishigaki 2010)" that will provide people with a securer and more affluent life with information and communication technology (ICT). One of the unique features of the project is to build a promising way of identifying essential social problems and formulating effective solutions

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for the promotion of social innovation (Ishigaki and Sashida 2013) based on systems methodologies (Checkland 1981; Jackson 2003) and cultural anthropological methods (Cefkin 2009; Spradley 1979). The project was intended to develop feasible policies to realize the purposeful activities of multiple stakeholders through fieldwork based on interviews and workshops in some case studies such as local agricultural revitalization and social welfare enhancement. Most of them, however, were not innovative solutions, which involve advanced and high-level mathematical technologies and artificial intelligence (AI). On the other hand, conventional mathematical approaches, which have been used as a promising way to resolve explicitly defined problems (Kira et al. 2017; Shinohara et al. 2013), cannot be applied to the ill-structured social problems directly. If researchers specializing in mathematics build an innovative solution, it is unlikely to be accepted by most stakeholders because there exists a cognitive gap with respect to social problems between the researchers and stakeholders. This makes it imperative that the researchers clearly understand problem situations, including the various aspects of conflicts among stakeholders who have different values, beliefs, and interests, before building a new technology to resolve a specific social problem.

In 2014 we started a new research project, which we call “social mathematics,” with the aim of resolving social issues based on mathematical technologies. The project aims to build a comprehensive approach from the identification of an essential problem to the creation of an innovative solution in a target field by utilizing both field intervention methods and advanced mathematical technologies and AI. In an effort to consider the approach, Kyushu University, Fujitsu Limited, and Fujitsu Laboratories Limited established the Fujitsu Social Mathematics Joint Research Unit within Kyushu University’s Institute of Mathematics for Industry (Fujitsu Press releases 2014). The new joint research department aims to create a novel methodology for social systems design based on social science research in fields such as economics and psychology, coupled with data utilization techniques such as mathematical analysis, optimization, and control. There are some notable case studies—such as congestion reduction at Fukuoka Airport (Fujitsu Press releases 2015), promoting relocation to Itoshima city (Fujitsu Press releases 2016), and supporting daycare admissions screening in Saitama city (Fujitsu Press releases 2017)—that have had the aim of building a social system model based on human psychological and behavioral factors and optimizing the various policies of the social system with the model.

This paper is organized as follows. Section 2.2 presents our research approach to resolve social issues based on mathematical technologies. In Sect. 2.3, we introduce some of the case studies that have been built up in our joint research department within Kyushu University in order to show the effectiveness of the research approach. Section 2.4 discusses findings and available knowledge concerned with developed technologies and the system design processes developed from our case studies. Lastly, Sect. 2.5 provides some concluding remarks and issues for future work.

2.2 Social Mathematics Approaches

The purpose of social mathematics is to optimize the design of social structures and policies by using a model of human behavior and psychology based on mathematical techniques. To realize a purposeful social system, we tried two approaches from the viewpoints of technological solutions and system design processes. First, we attempted to systematize technologies for social system design through integrating mathematical and AI technologies for analysis, optimization, and control with economic, psychological, and other social science research. It is difficult to realize purposeful social systems based only on data-driven technologies because they cannot accurately take into account a large variety of human behavior and psychology in the system. In our joint research unit, we set out to develop the following three techniques: (1) techniques for building models of social systems that mathematically describe human psychology and behavior, (2) techniques for designing policies and programs that are fair and have good public receptivity using the social system models, and (3) techniques for the visualization of the societal impact of the policies and programs that have been designed (Fig. 2.1).

Second, we considered the system design processes in order to connect social issues with technological elements through field intervention in a target system. In manufacturing fields, in general, researchers who are specialized in mathematical technologies and AI can understand a problem clearly when they begin developing a new technology. In social systems that include complex relationships between human characteristics, however, they cannot identify an essential problem that

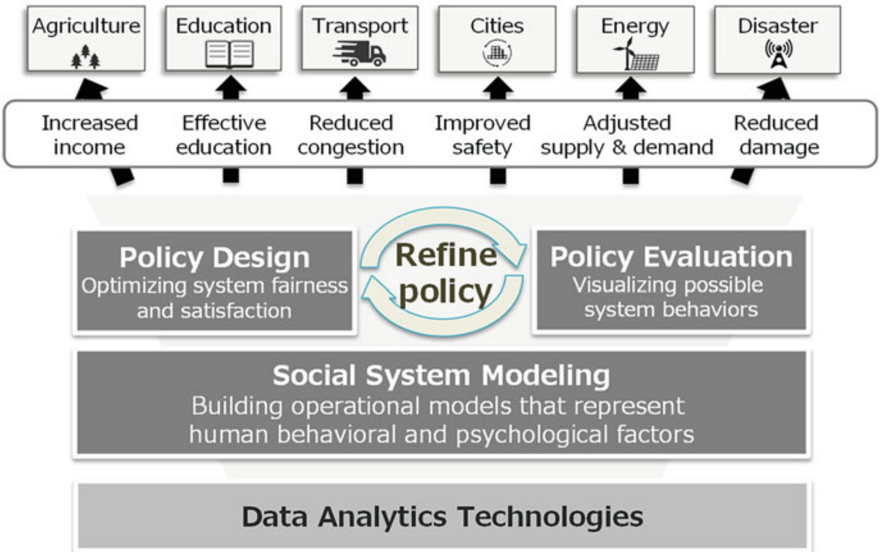

Fig. 2.1 Social mathematics approach and examples of social issues

could be resolved by their technologies. The main reason is that stakeholders who have various types of problem concerns as domain knowledge cannot explain them correctly. Therefore, in our joint research unit, the researchers themselves tried to understand stakeholders' problem concerns by using methods such as in-depth interviews, questionnaire surveys, and workshop techniques based on social scientific knowledge.

2.3 Case Studies

We tackled various types of case studies for resolving social issues in order to clarify the elements of our research approach and methodology. This section explains three cases in which we confronted the unique difficulties in resolving social issues based on mathematical technologies.

2.3.1 Congestion Reduction in a Place Where People Gather: The Case of Fukuoka Airport (Fujitsu Press Releases 2015; Yamada et al. 2017)

2.3.1.1 Background

Congestion reduction in a large-scale facility such as an airport, an event venue, or a stadium is a most important social issue. Fukuoka Airport, the gateway to the Kyushu region, is the third-largest airport in Japan after Haneda and Narita International Airport, serving about 20 million passengers in 2014. In particular, the number of passengers in the international terminal has increased due to a sharp rise in inbound travelers. As a result, the facilities in the terminal have become increasingly crowded, leading to the possibility of a decrease in passenger satisfaction due to this congestion. It has become vital for airport decision-makers to develop new policies—such as the introduction of new equipment and staff operation management—to improve the congestion situation.

2.3.1.2 Problem Situation

We focused on the departure floor in the international airport terminal, which consists of baggage X-ray inspection facilities, check-in counters, security check facilities, and departure examination facilities, as a first target system to consider new policies (Fig. 2.2). Passengers must pass all four types of facilities before they are able to board their flight, and they have different characteristics in terms of the time of their arrival at the terminal and the number of items of baggage they have with them. In particular, there is much uncertainty in the arrival time because it is

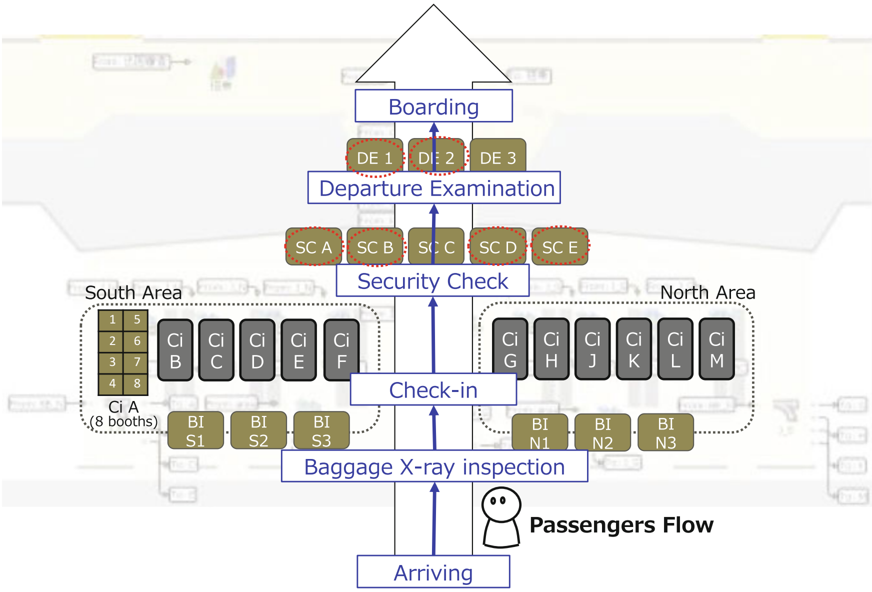

Fig. 2.2 Passengers flow of Fukuoka airport international terminal departure floor

affected by the state of other transit facilities such as buses and trains. It is thus hard to predict the effectiveness of new policies such as staff operation management and new equipment introduction in improving the congestion situation in consideration of the heterogeneous and uncertain elements of passengers.

2.3.1.3 System Design Process

In November 2014 we started to collect the concerns of stakeholders in the target system. The researchers, who are mathematics majors, themselves gave an hour interview per member to nine members in Fukuoka Airport Building Co. As a result, we identified four types of ideal situations relating to "comfort," "safety," "sales," and "liveliness" in the terminal. Then, the researchers analyzed the problem structure to identify the essential problem that should be resolved with system analysis methods (Miser and Quade 1985). For example, Fig. 2.3 shows the relationships between problem concerns leading to passenger discomfort. Based on the analysis results, we shared the problem structures in the terminal and then determined ways to improve the problem situation relevant to the increase in congestion, which is an obstruction to realizing all ideal situations, as part of our first phase of work. Finally, we built a mathematical model to represent the problem situation in the terminal and developed a simulator to visualize the effectiveness of alternative policies. As a result, Fukuoka Airport Building Co. understood the

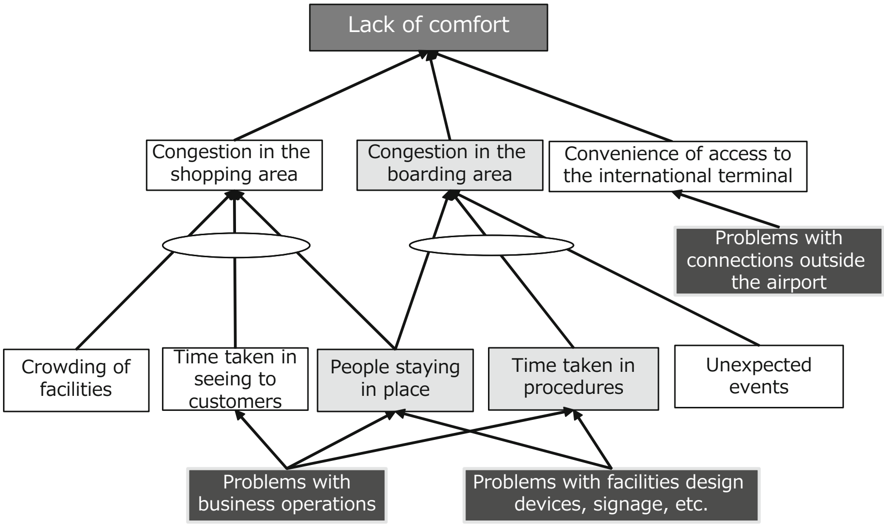

Fig. 2.3 Problem structure leading to passenger discomfort

value of our simulation model. We then commenced field trials using the model in September 2016.

Although the model can explain precisely passenger behaviors in a series of procedures before boarding, it is difficult to obtain complete data relevant to the model parameters. The main reason is that the data belongs to multiple stakeholders such as airlines and security companies and they were hesitant to disclose the data because of the difficulties this would cause due to the complicated procedures regarding the regulation of information management in their companies. We repeatedly explained the simulation tool from various viewpoints in an attempt to get them to understand its value, and consequently we were able to collect the complete data for the parameters. The calibration based on the data greatly improved the accuracy of simulation results. The results engendered in the stakeholders a cooperative attitude with respect to our field trials. Consequently, we were able to evaluate some concrete policies that we felt would reduce congestion in the airport by using the simulation tool with the data. In the last experimental trial (conducted in April 2017), we evaluated the effectiveness of a full-body scanner that had been introduced in security check facilities. The simulation results were able to reproduce real congestion situations, which can be useful for the decision-making of schedule management of the security check facilities.

2.3.2 *Promotion of Relocation from Urban Areas to Countryside: The Case of Itoshima City (Fujitsu Press Releases 2016)*

2.3.2.1 Background

Recently, the number of people who want to relocate from urban to more rural areas has been increasing. The Japanese government also promotes relocation in a bid to prevent a decrease in population. The city of Itoshima in the Japanese countryside is gaining attention from urbanites who want to relocate because of the ease of access to the nearest major city and its beautiful nature and landscapes. Each urbanite who wants to relocate to the city has diversified needs, and the city can fulfill many of these with its various types of areas such as seaside, mountains, fields, town areas, and isolated islands. Although relocation counseling sessions have often been held for the urbanites by the city, the officials cannot always provide adequate information corresponding to the customers' needs in a given consultation time for each urbanite. The city now hopes to build a new system that can provide useful information for all the urbanites.

2.3.2.2 Problem Situation

Most people who want to relocate to Itoshima do not recognize their own preference when choosing areas they want to move to. Moreover, some of them pursue a rural ideal, surrounded by forests and water, and do not understand the realities of daily life in such areas. At the counseling sessions, urbanites gradually come to learn the importance of elements such as shopping, hospital visits, and neighborly ties as officials introduce the features of some areas. The process of leading them to recognition of their preferences takes between 30 min and an hour. The officials thus cannot take time to provide more detailed information on issues such as finding employment, lifestyle, and housing without area information for relocation. The city wants to enable urbanites to recognize by themselves the specific conditions that are the realities of the place to which they want to move before attending the counseling session.

2.3.2.3 System Design Process

We began considering a system for effective consultation for relocation based on mathematical technologies and AI in August 2016. It was, however, difficult to determine a potential focal point for the system from the perspective of technology because there is no relocation data for the system development. Therefore, before examination of technologies used for the system, researchers specializing in AI themselves investigated the problem concerns through interviews with the officials about their troubles and the observation of the interaction process between officials and urbanites at the counseling event. Then, the investigation brought us to the problem situations described above. As a result, as our challenge we determined to develop an AI system that can extract the preferences of urbanites and recommend candidate areas to them before the counseling session.

We developed an area recommendation system by combining a mathematical model based on a discrete choice analysis often used in the field of marketing science and AI based on machine learning. The mathematical model derives the preferences from attributions such as gender, age class, and family structure by gaining virtual data of area selections through questionnaire surveys where no real relocation data is available. The system recommends appropriate areas corresponding to the preferences derived from the attributes according to the mathematical model. However, the accuracy of the relationship between the preferences and attributes is relatively low due to the use of virtual data. We thus impart a function that can revise the relationship by using feedback information for the areas recommended from the users to the system. As a result, the system automatically and gradually can improve the accuracy of area recommendations.

In November 2016 we started to verify the effectiveness of the system by making real urbanites use it at the counseling event. Contrary to our expectations, more than half of the urbanites assessed the value of the system as low. Along with city officials, we then held a workshop to reconsider the role of the system in the counseling sessions. Consequently, we successfully designed a collaborative model between the officials and our system (Fig. 2.4).

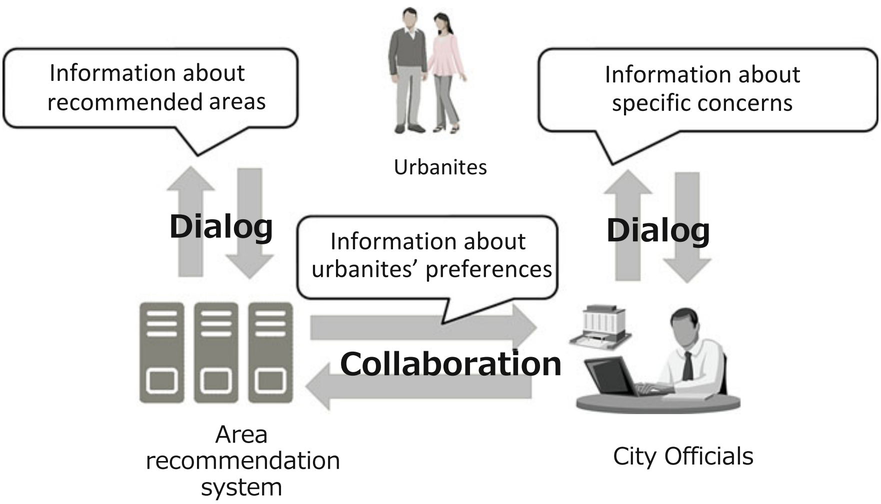

Fig. 2.4 Collaborative model between human and machine roles

We evaluated the efficacy of the system through a subject experiment from the viewpoint of technological issues in March 2017. About 100 urbanites who wanted to relocate to the countryside tried the system, and the log data the system used then showed the system could learn the relationship between the preferences and attributes and could finally recommend highly appropriate areas to users. However, the city officials and urbanites who used the system pointed out that the information provided by the system is difficult to understand. As a result, we are currently addressing the design of the system interface from the viewpoint of human-computer interaction (Weyers et al. 2017).

2.3.3 Support of Daycare Admissions Screening: The Case of Saitama City (Fujitsu Press Releases 2017)

2.3.3.1 Background

In an attempt to tackle the declining birth rate, the Japanese government enacted the Act on Child and Childcare Support in 2012. The Act, partially revised in April 2015, promotes the expansion of certified centers for early childhood education and care and childcare support services. However, serious challenges still exist in the field of childcare, such as the number of children on waiting lists for daycare centers. In particular, the complexity of daycare admissions screening, which results in children being assigned to a limited number of centers according to the various conditions of each family, is one of the major challenges because of the need to maintain fairness between children; in addition, it requires a high level of investment in time and human resources. In fact, there have been many cases where siblings were assigned to different daycare centers in some local government areas. It is clear that the admissions assignment process must be improved from the viewpoint of both accuracy and speed.

2.3.3.2 Problem Situation

The basic goal of daycare admissions screening is to satisfy the preferences of applicants according to the priority ranking of children in consideration of the number of places in each daycare center. In addition, each local government can incorporate more complex requirements—such as applicants who want their siblings assigned to the same daycare center and who want siblings assigned in the same period—in order to increase the satisfaction of applicants. Saitama city government has eight requirements concerning sibling admissions as well as the timing of the siblings' admissions. The screening rule thus became more complex, and consequently there are cases where multiple assignment patterns can fulfill the rule or no patterns fulfill the rule. This means the city officials are required to take a long time to carefully determine the assignment of applicants to be absolutely sure that the relevant rules have been correctly fulfilled.

Sibling

Sibling

	Child 1 Priority 1	Child 2 Priority 2	Child 3 Priority 3	Child 4 Priority 4	Meet the rule?
Assignment 1	Daycare A	Daycare A	Daycare B	Daycare B	×
Assignment 2	Daycare A	Daycare B	Daycare A	Daycare B	×
Assignment 3	Daycare A	Daycare B	Daycare B	Daycare A	✓
Assignment 4	Daycare B	Daycare A	Daycare A	Daycare B	✓
Assignment 5	Daycare B	Daycare A	Daycare B	Daycare A	×
Assignment 6	Daycare B	Daycare B	Daycare A	Daycare A	×

Fig. 2.5 Admissions decision using the rule (assignment 3 is optimal)

For example, Fig. 2.5 shows the case that considers assigning two sets of siblings to two daycare centers (daycares A and B) that accept two children each. In this case, there exist six possible combinations in the consideration of the number of places in each daycare center. Here, each child prefers daycare A to daycare B, but the applicants would prefer both their siblings go to daycare B rather than be split up. In this situation, assignments 3 and 4 both satisfy the rule, but assignment 3 that satisfies the preferences of child 1 (who has the highest priority ranking) is optimal.

Figure 2.5 is an example of easy problem setting. In a real situation, the table size is extremely large because the number of daycare centers and children can be larger. If five daycare preferences are listed for each of 8000 children, there will be 5 to the power of 8000 possible combinations. It would thus be difficult to determine the assignment satisfying the rule automatically, even using computers. In Saitama city, 20–30 officials took quite a few days to determine the assignment manually through trial and error.

2.3.3.3 System Design Process

In June 2015 we began to investigate the current scheme of daycare admissions screening and acquired the domain knowledge relevant to childcare support. In March 2016 the researchers specializing in mathematics themselves conducted interviews with officials in Saitama city to understand the detailed requirements and process in admissions screening and the ideal situations. As a result, we identified the problem situation mentioned above. Then, we built a mathematical model to represent the complex relationship between the requirements of applicants and the priority ranking and preferences of children based on game theory. Specifically, an assignment of each child is converted to pay off, and then an optimal assignment pattern, which maximizes the payoff for the applicants having higher priority, can be found.

However, we could not determine the system requirements because the city officials could not judge what kinds of constraint conditions were needed for our development system. Then, we repeatedly explained the model structures and possible input/output images to the city officials and consequently developed a system to find an optimal assignment in just seconds based on a mathematical model that represents the complex relationship between the applicants and an AI technology that accelerates the calculation speed. In January 2017 we commenced verification of the accuracy of the assignment derived from our system by using anonymized data for about 8000 children in Saitama city. In the early stages, we were unable to obtain a complete data set for the evaluation because the information of applicants in the database was updated daily. We therefore repeatedly confirmed what data we should use with the city officials. Finally, in August 2017 we were able to obtain a level of accuracy that was equivalent to the manual admissions screening conducted by the city officials. The officials said the results could be accepted as being trustworthy and as close to perfect as possible.

2.4 Discussion

This section examines the findings, established as a result of the three case studies, about the development technologies (Sect. 2.4.1) and system design processes (Sect. 2.4.2) to resolve complex social issues.

2.4.1 Development Technologies

As described in Sect. 2.2, we provided a conceptual framework consisting of techniques for modeling, designing, and evaluating social systems. The case studies showed specific elements that should be incorporated as a core set of technologies for each technique in the framework. We confirmed that knowledge in the fields of consumer behavior (Kardes et al. 2011), game theory (Fudenberg and Tirole 1991), and agent-based modeling (Gilbert 2007) is useful to represent human psychology and behavior through the case studies, and, moreover, mathematical optimization and control and social simulation methods (North and Macal 2007) can be important technologies for the design and evaluation of social systems, respectively. In our future research, we aim to refine and systematize the technology sets to resolve various types of social issues, and that would be achieved based on further appropriate case studies of real social issues.

2.4.2 System Design Processes

Next, we consider the system design processes that can be mainly classified into three steps: (1) identification of problem situations, (2) system development, and (3) system evaluation. We note that in all case studies, the researchers themselves implemented all steps. In step 1 they heard from stakeholders about their problem concerns directly based on interview and workshop methods in social scientific research. As a result, it was possible to successfully identify problem situations. Moreover, since the researchers could consider questions to the stakeholders in terms of the technological features, it was easy to define the essential problem that needed to be resolved. On the other hand, we faced some difficult situations described in steps 2 and 3 as follows.

2.4.2.1 Step 2 System Development

In cases 1 and 3, we were not able to obtain all information that was needed to determine system requirements in the early surveys. The main reason was that the stakeholders could not intuitively image the input/output data and system structure until they visually confirmed an actual or prototype system. In case 2, although the requirements were determined in the early stages, we needed to reconsider the requirements after the evaluation step. Along with the city officials, we reached consensus on the requirements, but the users could not understand the system structure because the system mechanism was too complex. We were thus obliged to redesign the user interface of the system to enable users to understand it more easily.

2.4.2.2 Step 3 System Evaluation

In case 1, we took a lot of time to acquire the data needed to evaluate our system from some stakeholders. They had to confirm the regulations regarding information management in their companies before they were permitted to provide the data to us. We were required to explain the effectiveness of our system to them in order to facilitate the data acquisition. However, we could not explicitly demonstrate the effectiveness of our system until evaluating it by using the data. Consequently, we had to explain the value of our system by using a sample data set and hypothetical scenarios, repeatedly. In case 2, the users did not have the motivation to use the system because they came to the counseling session to discuss their situation with the city officials. This meant we had to reconsider the evaluation process and redefine the role of our system and that of the city officials. In case 3, although we wanted to use the latest screening results to evaluate our system correctly, a complete data set for the evaluation was not available. The reason was that the information of applicants in the database was updated daily, making it difficult to determine what timing of data set should be used for the evaluation.

These considerations imply that social systems design with advanced mathematical/AI technologies has unique difficulties depending on the features of stakeholders and development systems in various design processes such as system requirements definition, the explanation of system structures and values, and data set acquisition. We still have not been able to systematize all considerations to build a methodological finding. However, in order to solve difficulties, at least, we need to foster cooperation from stakeholders through close communication with them and then to obtain detailed information about their activities. Thus, the most important point for social systems design can be said to be the gradual implementation of the system development and evaluation while alternating between social and technological perspectives.

2.5 Conclusion

This paper presented a novel research project to resolve complex social issues based on mathematical and AI technologies and explained the notable case studies in which we confronted the unique difficulties of applying the technologies to social issues. We confirmed that communication between the researchers specializing in mathematics and stakeholders in a target system is very important in developing a new system based on their technologies. In particular, communication could completely eliminate the discrepancy of cognition about problem situations between researchers and stakeholders. Moreover, we could discover some important technological elements that are needed for social system modeling, design, and evaluation policies by developing actual systems in the case studies.

No methodology for researchers has been developed to design social systems based on their technologies at the moment. In the step of development and evaluation of systems, there are different difficulties in each case, which we resolved by trial and error. The future direction of this study is to explore methodological issues of system design processes while undertaking more case studies in different situations.

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Chapter 3
Study on the Social Perspectives of Traffic Congestion in Sri Lanka Through Agent-Based Modeling and Simulation: Lessons Learned and Future Prospects

Chathura Rajapakse, Lakshika Amarasinghe, and Kushan Ratnayake

Abstract Traffic congestion is bringing in severe disadvantages to the economy of Sri Lanka. Fuel cost and wastage, air pollution, loss of productivity, as well as unpleasant sights in major cities are among key negative consequences. Lots of short- and long-term measures have been taken by the government through various controls and infrastructure development, but the problem seems to be remaining unsolved if not becoming worse. Alternatively, we propose to study the traffic congestion from a social perspective pertaining to the lifestyles and decision-making patterns of urban and suburban communities as well as the behaviors of drivers and pedestrians. We present the details of an agent-based simulation model developed to study the impact of seepage behavior, which means the smaller vehicles moving forward through the gaps between larger vehicles without following the lanes in the traffic congestion. We further discuss a prospective future research along the same direction, which aims at predicting the impact of the growing motor-biking culture on the urban traffic congestion in Sri Lanka.

Keywords Agent-based modeling · Social simulation · Seepage behavior · Traffic congestion · Swarm intelligence · Sri Lanka

3.1 Introduction

Traffic congestion is a serious issue Sri Lanka is currently facing, which can be attributed to various social and economic changes taking place in the country such as the complex needs arising from urbanization as well as the increase of the household income. As projected by the Ministry of Transport, Sri Lanka (2014), the

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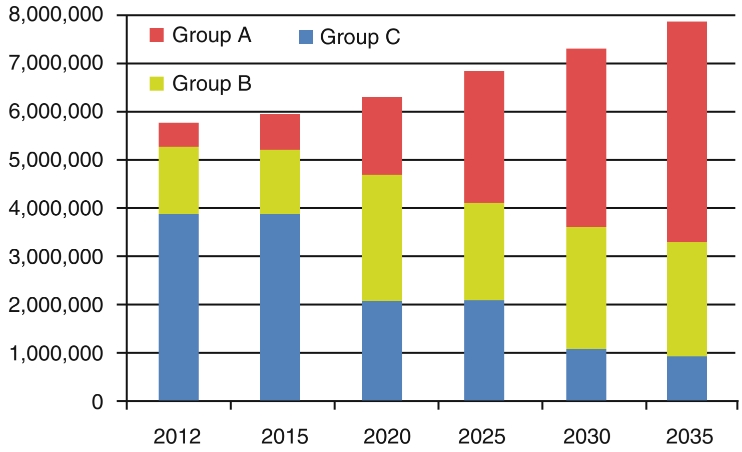

Fig. 3.1 Projected population based on income according to a home visit survey done under the urban transport system development project by the Japan International Cooperation Agency for the Ministry of Transport in Sri Lanka

household income in the Western province increases rapidly making the percentage of households with a monthly income more than Rs 80,000 (Group A) grow from 7.2% in 2012 to 56.3% in 2035. Furthermore, according to the same projection, the number of households with a monthly income less than Rs 40,000 (Group C) will decline from 67.8% in 2012 to 12.5% in 2035. This rapid expansion of households with higher income would cause an increase in the ownership of private modes of transport such as private cars and motorbikes (Ministry of Transport, Sri Lanka 2014). The motor tricycle, which is also known among tourists as the tuk-tuk, is another popular private mode of transport among urban and suburban households. This increased number of private vehicles creates a significant demand for road access and, hence, contributes largely to the traffic congestion (Ministry of Transport, Sri Lanka 2014) (Fig. 3.1).

According to a World Bank report on urbanization in South Asian region, urbanization in Sri Lanka exhibits different characteristics than the rest of the countries in the region (World Bank 2015). Sri Lanka has a medium-level human development index (HDI), largely due to its publicly owned free education and healthcare system. Compared to other countries in the region, Sri Lankan population exhibits a reluctance to migrate into cities looking for better lives mainly due to the fact that they have most of all urban facilities in places where they live (World Bank 2015). According to the World Bank (2015), in Sri Lanka, instead of rural people moving into cities looking for a better living, a "messy" urbanization is reflected in patterns of sprawl and ribbon development with evidence of rapid growth on the periphery of, in particular, the Colombo metropolitan region and along major transport arteries. This leads to the expansion of urban living to administratively non-urban areas (i.e., areas not belonging to municipal councils).

The sprawl and ribbon development in Sri Lanka is reflected in many observations. The road network went through a rapid development during the past decade after the war ended in 2009 making the residents who own lands on roadside to reconstruct their houses as appropriate for dual purposes, i.e., for both living and business. This move is reflected by the number of new shops, supermarkets, hotels, restaurants, and other kinds of businesses being started in newly constructed two- or three-story buildings facing the main roads in rapid pace. Another interesting phenomenon to observe is the demand for the lands, houses, and apartments in cities and suburban areas. According to a recent report on LMD, which is a leading business magazine in Sri Lanka, even in major cities like Colombo, Kandy, and Galle, the number of inquiries for houses largely supersedes the number of inquiries for apartments (LMD 2018). This could largely be attributed to the high cost of affording an apartment in the city (LMD 2018), but another possible reason, though there is no evidence about any surveys done, would be the established mind-set of people about living in their own houses. Furthermore, the growing number of online real estate advertisements reflects a demand for residential properties, from which the public transportation networks are not easily accessible without a private mode of transportation.[1] This sprawl kind of development taking place in the peripherals of major cities accounts largely to a faster expansion of urban areas. In fact, according to the World Bank (2015), Sri Lanka has the fastest expansion of urban areas in the South Asian region, as measured using nighttime light data, relatively to urban population, with a ratio of more than seven.

As anticipated due to the increase of household income as well as sprawl development, the Ministry of Transport and Civil Aviation's data (Ministry of Transport, Sri Lanka 2017) clearly reflects a significant increase in the personal modes of transportation in the country. Figure 3.2 depicts the total number of vehicles registered in Sri Lanka by category, and it reflects a steady growth in the number of motorcycles in the country. Notably, the second and third place goes to motor tricycles (tuk-tuks) and cars, respectively. Moreover, the number of new vehicles registered in each year confirms this idea. As depicted by Fig. 3.3, the number of new motorcycles registered supersedes all other vehicles by a significant margin. The sudden spike in total new vehicle registrations is due to tax reforms in 2014, but the recent tax increments have put the growth in control. However, the government announced a tax reduction on small trucks, two-door trucks, and motorcycles below 150 cc in 2017, which will keep the trend on motorbikes going.

The traffic congestion in Sri Lanka (or even elsewhere) is not dependent purely on the ownership of private modes of transportation. It rather depends on the way individuals select their modes of transportation as well as the way they use the roads and other infrastructure when they commute. For example, due to the poor-quality public transportation system, individuals who live in the peripheral areas of Colombo City and work in public and private organizations in Colombo City

[1] Bicycle is not a popular mode of short-distance personal transportation among the middle class in Sri Lanka unlike in countries like Japan.

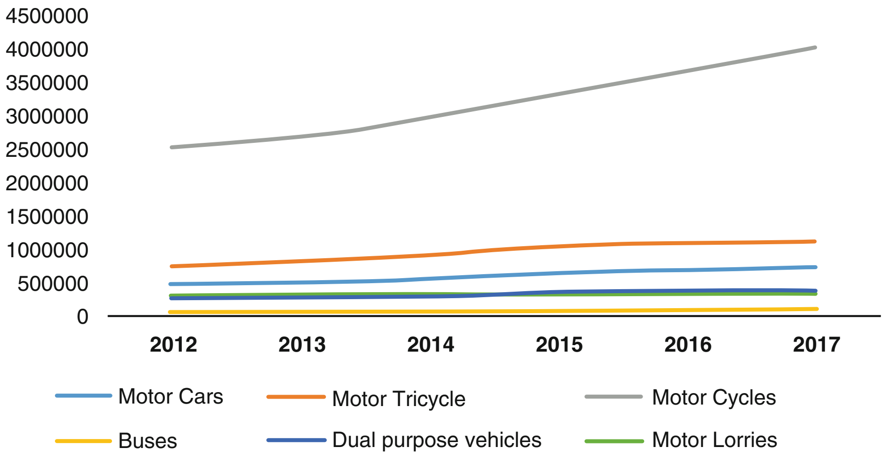

Fig. 3.2 The change of total number of vehicles registered by type

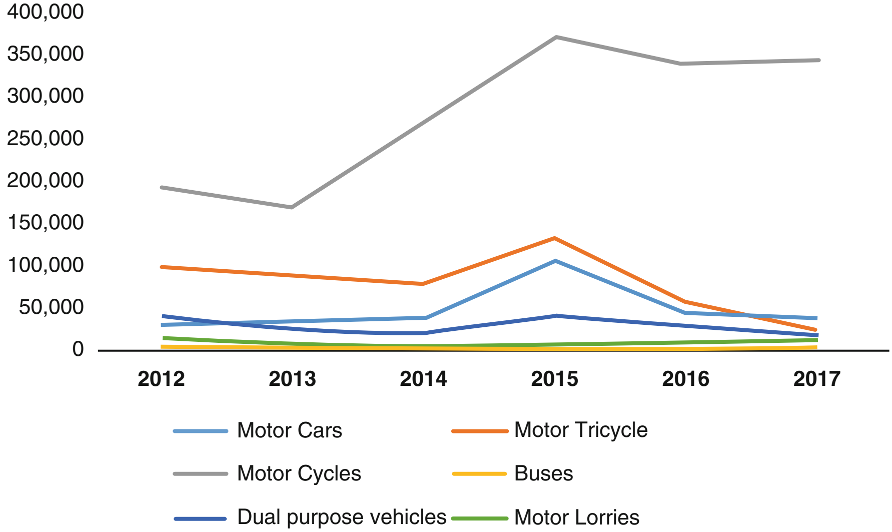

Fig. 3.3 The pattern of new vehicle registrations by type

increasingly use private modes of transportation for travelling to their respective workplaces daily. Especially, the younger male community largely uses motorbikes as their transportation mode to go to work. According to a report in indi.ca (2015), about 500,000 vehicles enter Colombo City every day, from which more than 85% are private vehicles. Moreover, out of those 85%, 38% are cars, 26% are motor tricycles, and 23% are motorbikes. According to the Ministry of Transport, Sri Lanka (2014), this trend will continue if the government does not take actions to develop the public transportation system. Another interesting observation, yet not adequately researched, is the increasing trend among females to ride motorbikes. The sprawl development and the necessity to frequently make trips to main roads and cities to get household and children's needs fulfilled may intensify the requirements of females to opt for motorbike riding. It is also possible to see multiple competing firms importing smaller low-cost motor scooters with low-power engines and offering to the market with attractive promotional packages. As these bikes are more affordable to a larger community, they appear to be an attractive solution to commuting needs.

Inevitably, this brings in lots of heterogeneity to the traffic flow such as vehicle heterogeneity, speed heterogeneity, as well as driver heterogeneity. This heterogeneity is a key determinant of the congestion as it disturbs the order of the traffic flow. Vehicles with low-power engines, such as motor tricycles and bikes, and even lorries cannot speed up in par with other vehicles, which makes long tails of traffic on roads, especially those having single lanes. Heterogeneous vehicle types with varying sizes make it difficult to maintain proper lanes in the traffic flow. This leads to the seepage behavior (Agarwal and Lämmel 2015) where smaller vehicles tend to move through vacant spaces between larger vehicles making the traffic flow largely unorganized. This behavior is quite apparent during the rush hour, especially among smaller vehicles such as motorbikes, motor tricycles, small cars, and even light trucks. Furthermore, the unordered traffic movements at the intersections are another factor that largely affects the congestion (Ministry of Transport 2014). Even though not proven with well-formulated scientific studies, a common observation and a widely heard perception is that a majority of the drivers of motorbikes and motor tricycles tend to violate highway codes. This is partly reflected by the accident data (Ministry of Transport 2017) depicted by Fig. 3.4. Improper parking as well as, though not related to heterogeneity, the pedestrian behaviors too largely affects the traffic congestion in Sri Lanka (Ministry of Transport 2014).

However, there is a large gap in scientific research regarding the emerging patterns of urban mobility and their impact on the congestion as a whole. For example, what is the impact of seepage behavior on traffic congestion? Does it help the majority to move faster or does it hold the entire traffic longer? And, where would this growing popularity of motorbike riding end up at? Will it lead to the creation of motorbike swarms in Colombo and its suburbans, which are common in Ho Chi Minh, Hanoi, or Jakarta? Understanding these dynamics and having predictions on their consequences would make policy makers able to take effective decisions on urban planning and traffic control. We propose and promote computational intelligence-based research to study the impact of micro-level dynamics of urban mobility in Sri Lanka to understand the emerging macro-level traffic patterns using agent-based modeling and simulation approach. This paper presents the results of two agent-based simulation studies conducted to study the impacts of seepage behavior and pedestrian movement patterns on traffic congestion using a suburban town closer to Colombo as the test-bed. The paper also presents some planned future work extending the work of the previous two studies to make predictions regarding the future congestion.

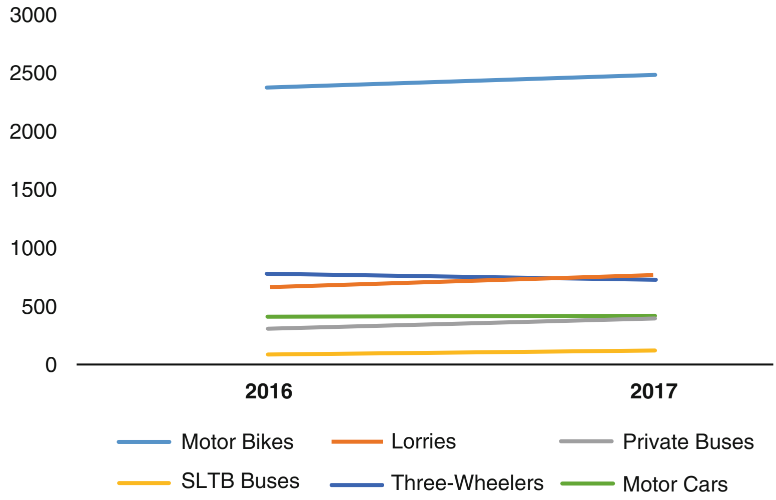

Fig. 3.4 Number of accidents by vehicle types in 2016 and 2017

3.2 Complexity, Agent-Based Modeling, and Traffic Simulation

Agent-based modeling (ABM) is a computational technique as well as a research approach to study real-world complex systems. In other words, ABM is a popular approach in solving complex problems in the real world. Complex problems characterize emergent phenomena, which are difficult to understand by simple analysis through decomposition. Formation of traffic, fluctuations of share prices at the stock markets, as well as opinion dynamics of the public regarding candidates contesting at an election are examples for emergent phenomena in complex social and economic systems. Glouberman and Zimmerman (2002) provide a very good comparison between simple, complicated, and complex problems, as depicted by Table 3.1,[2] which helps in understanding the characteristics of complex problems.

Making policies to deal with some complex problems is highly challenging. The Australian Public Service Commission, in their interesting discussion paper (Australian Public Service Commission 2012), calls such complex problems "wicked problems," which, as they say, are not in the sense of evil but rather as an issue highly resistant to resolution. According to the Australian Public Service Commission (2012), the characteristics of wicked problems are:

1. Wicked problems are difficult to clearly define.
2. Wicked problems have many interdependencies and are often multi-causal.
3. Attempts to address wicked problems often lead to unforeseen consequences.

[2]There is some evidence of a hesitation to accept "raising a child" as a problem.

Table 3.1 A comparison between simple, complicated, and complex problems

Simple problem	Complicated problem	Complex problem
E.g., following a recipe	*E.g., sending a rocket to the moon*	*E.g., raising a child*
The recipe is essential	Formulae are critical and necessary	Formulae have a limited application
Recipes are tested to assure easy replication	Sending one rocket increases assurance that the next will be ok	Raising one child provides experience but no assurance of success with the next
No particular expertise is required. But cooking expertise increases success rate	High levels of expertise in a variety of fields are necessary for success	Expertise can contribute but is neither necessary nor sufficient to assure success
Recipes produce standardized products	Rockets are similar in critical ways	Every child is unique and must be understood as an individual
The best recipes give good results every time	There is a high degree of certainty of outcome	Uncertainty of outcome remains
Optimistic approach to problem is possible	Optimistic approach to problem is possible	Optimistic approach to problem is possible

4. Wicked problems are often not stable.
5. Wicked problems usually have no clear solution.
6. Wicked problems are socially complex.
7. Wicked problems hardly ever sit conveniently within the responsibility of any one organization.
8. Wicked problems involve changing behavior.
9. Some wicked problems are characterized by chronic policy failure

Complex problems can encompass both complicated and simple subsidiary problems, but are not reducible to either, since they too have special requirements, including an understanding of unique local conditions, interdependency with the added attribute of nonlinearity, and a capacity to adapt as conditions change [9]. According to the Australian Public Service Commission (2012), attempts to solve complex problems require a holistic approach than a partial or linear thinking approach. Therefore, the systems thinking approach is a more appropriate approach in addressing complex problems. In other words, the characteristic emerging phenomena of complex problems could be thought of as resulting from the dynamics of complex adaptive systems, making the study of underlying complex adaptive systems fundamental in order to find viable solutions to the respective complex problems.

As mentioned before, formation of traffic could be seen as an emergent phenomenon of a complex problem solving which requires to understand the underlying complex system. Going by the characteristics mentioned in Australian Public Service Commission (2012), "traffic" is a complex problem that fits well into the scope of wicked problems as it has almost every characteristic of wicked problems. Much of the complexity of the problem of traffic, hence, could be attributed to its social complexity than the technical complexity, which makes it hard to address. Social complexity emphasizes the social aspects of a complex (wicked) problem. For example, climate change is an example for a wicked problem where there is wide scientific agreement about the need to reduce our carbon emissions. Technically this is not difficult to achieve, but socially and politically it is proving to be much more difficult (Stuart 2018). In other words, it is difficult to control unsustainable lifestyles of individuals and households which demand harmful patterns of consumption and production (Australian Public Service Commission 2012). This is not so different in the case of traffic as well. It could be reduced technically by improving infrastructure, developing public transport systems, building planned cities, or even imposing rules and regulations, but if the crowd does not use the public infrastructure and their private transport modes with a discipline and sense, as well as if the policy makers do not try to understand the social facets of the problem, the problem would still tend to pursue. Thus social complexity could be argued as vital to address in order to solve the wicked problem of traffic. This gives the necessary validity to the study of the underlying social systems to understand the social complexity of the traffic problem.

The characteristics of complex systems make them particularly difficult to understand as they are comprised of multiple levels of organization that often depend on local interactions. Agent-based modeling offers a viable methodology to model components of a complex system at different levels of organization as well as their local interactions and thereby to study the possible causes of visible macro-level emergent patterns. As Alan Kay says, inventing the future is the best way to predict it (Terano 2008) which means to generate the future to see how it looks like. This generative approach in the study of complex social systems is largely supported by the agent-based modeling technology (Epstein 2006). It enables to create would-be worlds (Casti 1997) of such complex social systems in the form of computer simulations, in which a group of heterogeneous, autonomous, bounded rational agents interact locally in an explicit space (Epstein 2006). An agent in this approach is an abstract representation of characteristics and behaviors of an individual or an object (such as a car or a firm) in a real-world social system, whose design could be implemented as a software component. An agent-based model of a complex social system is then a computational representation of the real system that mimics its micro-level individual behaviors and exhibits its emergent macro-level patterns. The creation of silicon surrogates of real-world complex systems allows us to perform controlled repeatable experiments on the real McCoy (Casti 1999).

Agent-based modeling for traffic simulation is not a novel approach (Balmer et al. 2004; Cetin et al. 2003). However, to the best of our knowledge, there is very few such research done for the Sri Lankan context. One notable study (Rakkesh et al. 2015) has investigated the optimal traffic light cycles using multi-agent systems and swarm intelligence approaches with the objectives of reducing the waiting times and journey time of vehicles and qualitatively improving smooth traffic flow over the regions. Apart from that, an approach similar to agent-based modeling and simulation has been discussed in Rzevski (2008) on a general context. In the subsequent sections, we present some agent-based simulation studies we conducted to investigate traffic-related problems in Sri Lanka as well as some future prospects of the agent-based traffic simulations.

3.3 The Seepage Behavior and Its Impact on Road Traffic

When it comes to Sri Lankan urban traffic, it is mostly heterogeneous with different types of vehicles (motor cars, buses, motor bicycles, and three-wheelers), which differ in their static characteristic, vehicle size, as well as dynamic characteristics: speed, acceleration, maneuverability, and driver behavior. Due to their size and ability to move through small gaps between other vehicles, motor bicycles and three-wheelers seem to be less sensitive to the traffic flow, but their behaviors mostly affect the flow of the other vehicles. In Sri Lanka, often motorcycles and three-wheelers do not wait along with the other vehicles when the traffic is not moving. These two types of vehicle tend to have weak lane discipline and perform dynamic virtual lane-based movements or non-lane based movements (Lee and Wong 2016) in high-congested traffic conditions, while other vehicles follow *vehicle following* behavior (Pipes 1953). In literature, this behavior is defined as *seepage behavior, lane filtering, lane splitting, lane sharing, or percolation* (Agarwal and Lämmel 2015; Lee and Wong 2016) which is common in all countries that have mixed traffic condition (Agarwal and Lämmel 2015). Figure 3.5 depicts the difference between passing behavior and seepage behavior, whereas Fig. 3.6 shows a real image of the seepage behavior of motor tricycle drivers.

The aim of this study was to model a reliable, detailed microscopic traffic simulator using agent-based modeling to simulate Sri Lankan mixed urban traffic congestion. The effect of the drivers' behaviors, mainly seepage and vehicle following, was taken into consideration when designing the model. In this study, individual vehicles and pedestrians were modeled as software agents who have a set of individual (i.e., micro-level) behavioral rules. When these agents were put together, they behaved as the vehicles and pedestrians behave in the real world interacting with each other giving rise to emergent macro-level patterns, which we call traffic congestions. The effect of the drivers' behaviors, mainly seepage and vehicle following, was taken into consideration when designing the model. Apart from drivers, pedestrians are other users of the road. As the pedestrians' behavior is also an important determinant of the congestion, pedestrians' *road-crossing behavior* was added to the model as an extension to make the results more accurate. The simulator was calibrated and tested with real data taken from urban traffic flow of Kiribathgoda junction, which is a suburban city in the Western province of Sri Lanka with heavy congestions in the rush hours to ensure that the results are plausible. The process overview of the model is illustrated by Fig. 3.7.

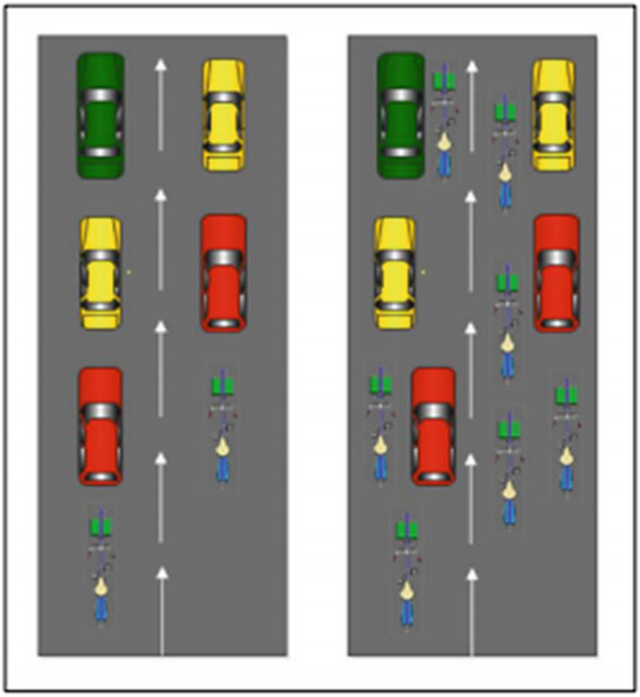

Fig. 3.5 Passing behavior vs. seepage behavior

The key design concepts of the model are as follows:

Emergence The emergence of the model is traffic congestion which is caused by individuals of the environment: vehicles, small vehicles, pedestrians, and traffic lights. The individual's behavior was represented by empirical and theoretical rules describing, for example, seepage behavior and vehicle following behavior.

Adaptation Adaptation was not modeled directly in the model. Though agents' responses vary with environmental conditions, the model assumes that the agent responses are fixed.

Objectives Agents were not designed to seek for maximizing "success "or the probability of a particular objective. They were instead modeled as autonomous agents encountering a number of decision-making points (speed, stopping distance, etc.). At each decision point, agents make decisions in accordance with the observed data, which were used to model the decision-making process.

Learning Learning was not represented in the model, which means the rules that the agents use to make decisions do not change over time. Agents' responses evolve over time based on changing environmental and other conditions according to fixed decision rules.

Fig. 3.6 Real seepage behavior of motor tricycles

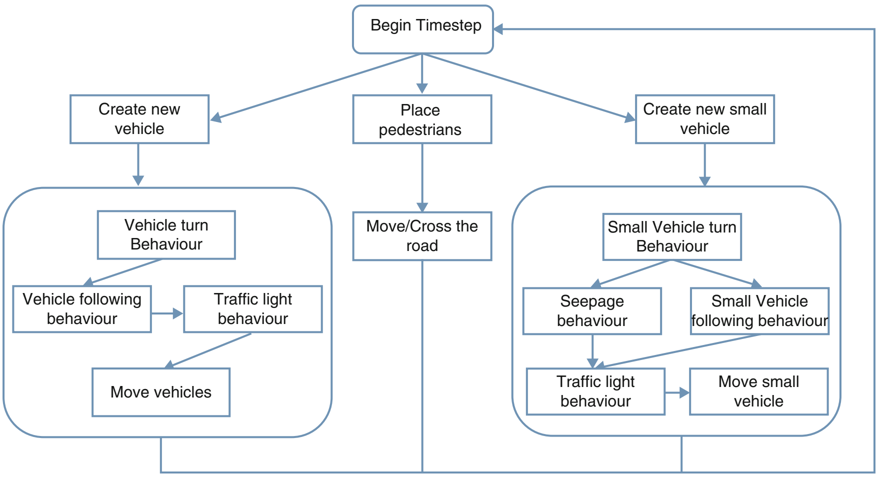

Fig. 3.7 Process overview of the model

Sensing Individuals are assumed to know their own characteristics. Each vehicle and small vehicle agent was made aware of max acceleration, max deceleration, max speed, etc. This information informs person agent's decisions. Global characteristics (vehicle/small vehicle rate) are not visible to the agents in the model.

Interaction Agents interact with each other (vehicles, small vehicles, pedestrians) and with their environment (roads, traffic lights, crossings). The primary interactions between vehicle agents are a vehicle following behavior and seepage behavior of small vehicles. The vehicles move along the road by following their leader, while small vehicles move the gaps between normal vehicles according to the state variables associated with each agent. Both vehicle types stop at traffic lights and crossings when needed. Pedestrians move along the sidewalks and cross the road by adhering to the lights.

Collectives Three types of collectives exist in the model: vehicle agents, small vehicle agents, and pedestrians. All the collectives possess their own unique state variables.

Observation Observation includes the graphical display of vehicle and pedestrians' behaviors in a road network, flow-density relationship, time-space relationship, and journey delays with and without the seepage behavior.

The state variables and their default values are described in Table 3.2.

The model has new sub-models, namely, create vehicles (and small vehicles), vehicle turn, follow vehicle and move, seepage behavior and move, traffic light behavior, create pedestrians, and move pedestrians. Vehicles are created according to the input parameter values, and their moving direction is determined by the direction of the road patch they are on. Turning is based on the vehicle ahead or the directions set by the road.

The vehicle following model is based on the anti-collision concept and was inspired by the Gipps' model and fuzzy logic ideas (Lansdowne 2006).

```
IF (any vehicles in front within current stopping distance)
               Slow down (using max deceleration)
ELSE
               Speed up (using max acceleration, restricted by
                 maximum speed)
```

This algorithm was intended to model the core features of vehicle interaction, by making drivers drive in such a way that they would always able to stop in time if the vehicle in front stopped. It appears to give drivers the ability to follow the well-known two-second rule, where drivers attempt to keep at least 2 s worth of distance between vehicles. It also makes vehicles slow-to-start, i.e., they do not move until the vehicle ahead is a certain distance away.

The seepage behavior model for modeling small vehicles' behavior is derived from the framework proposed by Agarwal and Lämmel (2015).

```
IF (any vehicles in front within current stopping distance
      or queue in front?)
```

Table 3.2 State variables of the model

Agent	Variable name	Default value	Description
(General)	Road?		Patches belong to roads are given the value True
	meaning		Patches belong to the sidewalks are given the value True
	directions		Directions values are assigned to patches on roads (N/E/S/W)
	speed-limit	0	Speed limit on the patch
Counter agent	last-vehicle	0	Increments when a vehicle passes the counter
	last-small-vehicle	0	Increments when a small vehicle passes the counter
Vehicle agent	LAST_PLOT_X	0	Last coordinate of the vehicle
	LAST_TURN_PATCH	none	Information about the last patch the vehicle made a turn at
	TIME_ENTERED		Uses the simulated time that the vehicle entered
	desired-speed	0	Desired speed of the vehicle
	max-speed	13	Maximum possible speed
	max-acceleration	2 + Random	Maximum possible acceleration value
	max-deceleration	5 + Random	Maximum possible deceleration value
Small vehicle	LAST_PLOT_X	0	Last coordinate of the vehicle
	LAST_TURN_PATCH	none	Information about the last patch the vehicle made a turn at
	TIME_ENTERED		Uses the simulated time that the vehicle entered
	bi-desired-speed	0	Desired speed of the vehicle
	bi-max-speed	8	Maximum possible speed
	bi-max-acceleration	4 + Random	Maximum possible acceleration value
	max-deceleration	5 + Random	Maximum possible deceleration value
Traffic light	green-time		Time the green light is on
	red-time		Time the red light is on
	yellow-time	3	Time the yellow light is on
Person	speed	Random below 7	walking speed
	walk-time	Random below 100	Total walk time of the agent
	crossing	0	Can take 0, 1, 2, 3 to determine how much the road is crossed

```
IF (any vehicles in left or right within current stopping
               distance) make a lateral movement to left or
               right - speed up using max acceleration
ELSE (do not make lateral movement - slow down using deceleration)
ELSE
IF (any vehicles in left or right within current stopping
                distance) make a lateral movement to left or
              right - speed up using max acceleration
ELSE (do not make lateral movement - slow down using deceleration)
```

This algorithm was intended to model the common behavior of small vehicles in Sri Lanka which are moving through the gap between other vehicles rather than waiting and following the leading vehicle.

The traffic lights operate according to the input parameter values. Vehicles check on the lights in their visible distance ahead as well as possible pedestrian movements before passing the lights. Pedestrians move along the sidewalks until their walk time finishes. If the walk time exceeds assigned walk time, they try to cross the road. To cross the road, pedestrian has to find a crossing and has to wait at waiting points and adhere if there is a controller to control the pedestrians and vehicles. If there is no controller, pedestrians have to wait until the vehicle stops at the crossings.

The model was tested after implementation for runtime errors, realistic behavior of individuals (microscopic), and valid overall behavior (macroscopic). One key result of the model includes the impact of the seepage behavior getting obvious. The time-space graphs illustrated in Figs. 3.8 and 3.9 illustrate the outcomes of the model when there is no seepage behavior (only vehicle following behavior) and when the small vehicles exhibit the seepage behavior, respectively.

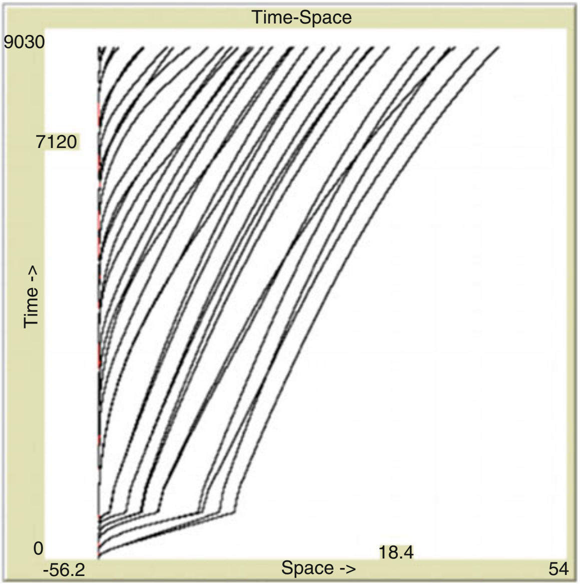

Fig. 3.8 Model outcome when there is only vehicle following behavior

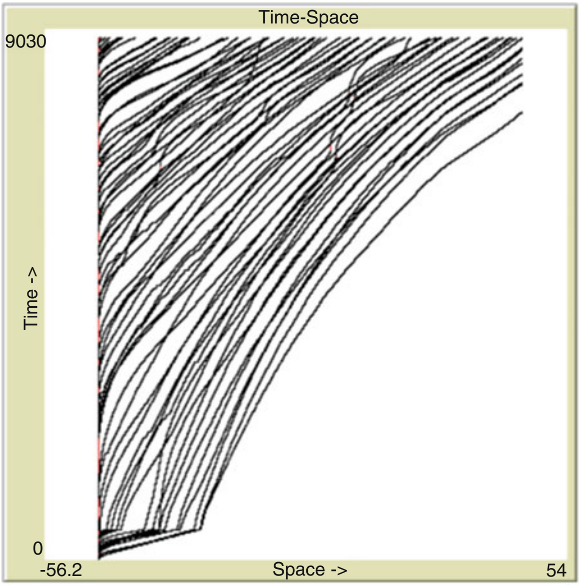

Fig. 3.9 Model outcome when there is seepage behavior

Figure 3.10 illustrates a very interesting and notable result from this study. The corresponding experiment was conducted in two phases: phase 1 with seepage behavior and phase 2 without seepage behavior. The red dots on the figure correspond to the small vehicles, whereas the black dots represent the other vehicles. According to Fig. 3.10, the seepage behavior delays the journey time of all vehicles including the small vehicles. This is a phenomenon that needs further investigation as well as attention of law-enforcing organizations and policy makers in order to control the traffic congestion.

This research was extended as an overall case study for investigating better traffic planning scenarios to reduce the traffic at the Kiribathgoda junction in Western province of Sri Lanka. There the driver behaviors, pedestrian behaviors, as well as traffic conditions at junctions were considered. The research work presented in this paper is very simple but have strong implications on agent-based modeling based on traffic simulation studies in the Sri Lankan context. They could be considered as eye openers as well as starting points for more serious and concrete simulation studies that deeply investigate the impact of complex social system dynamics on the urban traffic congestion in Sri Lanka.

3.4 Future Prospects

One of the key parties involved in the seepage behavior is motorcyclists. Due to the smaller size and higher visibility, the riders tend to move forward through every possible gap ignoring all lane rules. We observe an upward and popular trend in the

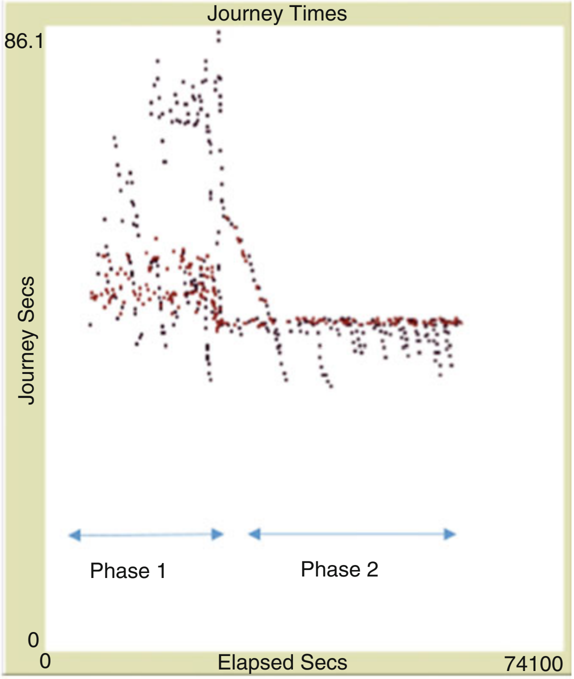

Fig. 3.10 The overall journey time comparison with and without seepage behavior

use of motorbikes among young males as their mode of transportation. Moreover, there is a noticeable tendency among females including young mothers to shift into motorbike riding for their transport needs such as taking their children to and from schools, sports practices, and tuition classes.[3] The vendors on the other hand largely support this transition importing a wide variety of motorbikes including more affordable low-powered scooters suitable for females. Motorbike sales outlets appear along main roads as well as suburban towns in rapid pace, each of which offers attractive promotions and easy payment schemes making it easier for the lower-middle-class families to afford a bike. Further looking at the exponential growth in the motorbike sales, as apparent in Fig. 3.3, some vendors have even set up local motorbike assembly plants to cater the high demand. Though the tax policies have been changed time to time, perhaps expecting some control, the increase in the household income may lead this upward trend to continue.

Motorbike swarms are a noticeable feature in the major cities of countries like Vietnam and Indonesia, which contribute heavily to the unorganized traffic flow, congestion, pollution, as well as distortion of the scenic beauty of cities. According to Freire (2009), motorbikes are literally everywhere in Vietnam and have been perfectly integrated into the social and economic life. They further mention that the

[3]Receiving private tuition is popular among students taking competitive exams at various levels of primary and secondary education in Sri Lanka.

motorbike appears to be the icon of the renovation policy launched in the country in 1986, which is known under the name *Doi Moi*. In other words, they argue that the motorbike symbolizes the consumerism in the socially transformed Vietnam after economic reforms. According to Hansen (2017) too, motorbike swarms reflect a relatively recent phenomenon after 1986 economic reforms. However, they observe that although motorbikes still dominate in Hanoi, the car has overtaken the throne as the main aspirational and positional good, and currently automobility is becoming progressively normalized. Both these observations are important for our ongoing research on the prevailing motorbike riding culture in Sri Lanka.

We observe both noticeable similarities and differences between Sri Lanka and Vietnam. On one hand, similar to 1986 economic reforms in Vietnam, the postwar Sri Lanka is experiencing a social and economic transformation in its transition from a low-income country to a middle-income country. However, the automobility or car-based transportation was an apparent feature in Sri Lanka for several decades largely due to the poor condition of the public transport system as well as the lack of any sound attempts to improve it as compatible to the aspirations of the middle class. Though the large income differences had kept a majority away from using private modes of transportation compelling them to use poor public transportation, the ongoing changes in household income levels have a high potential in making them joining the transportation system with a private vehicle, which is very likely to be a motorbike. As we understand, this is what we observe in the numbers of increasing new motorbike registrations, sales outlets, promotional packages, as well as female riders. As the impact of this change on the traffic congestion could be significant, we believe a systematic study on the growth of motorbike riding in Sri Lanka is a timely need.

Thus, our primary research question is whether this ongoing shift to motorbike riding ends up in having motorbike swarms on Sri Lankan roads as well. In order to do this prediction, we plan to create a would-be world using agent-based modeling and simulation. The proposed study is twofold. First we plan to conduct a survey among middle-income households to understand their usual transport requirements and the way they make decisions to select their mode of transportation. Based on the data collected from the survey, we plan to model the micro-level interactions to investigate the patterns of new motorcyclists joining the transportation system. Second, we wish to see the overall impact of the observations in the first phase of the study on the traffic congestion. Given that there are a large number of cars as well as motor tricycles on roads, the increasing number of motorbikes will drastically affect the flow of traffic in the future. This will be further intensified by the seepage behavior giving unexpected results in the congestion.

3.5 Conclusion

The core idea behind this paper is the possibility of using agent-based modeling and simulation technique to study complex social systems for the quest of solutions to the prevailing issue of traffic congestion in Sri Lanka. Unarguably, the poor public transportation system largely affects the congestion in Sri Lanka. Despite prevailing opinions of public as well as experts, there are no sound attempts to improve the public transportation system. Under these circumstances it is unavoidable that the public attempts to switch into personal modes of transportation as the quality of the public transport systems does not comply with their aspirations. Though there are a number of notable investments to develop infrastructure to control traffic such as building flyover bridges, constructing bypass roads, establishing priority lanes for buses, and widening roads, the number of studies reported that investigate the underlying social subsystem of drivers and pedestrians is largely insignificant. Through this paper, we have presented our views on the importance of studying the complex social subsystem of individuals, especially in urban households, to control traffic congestion. We have also presented the results of our investigation on one social characteristic of drivers of small vehicles, which is called the seepage behavior using the agent-based modeling and simulation technique.

According to the study on the seepage behavior, there are several notable implications to the law-enforcing agencies and policy makers. According to the results, the seepage behavior increases the travel time of everybody including the small vehicles that cause the issue. As this is a clearly observable phenomenon everyday everywhere in major cities of Sri Lanka, especially with the involvement of motorbike and motor tricycle drivers, we propose to have some strict controls on this behavior. These controls could be in the forms of enforcing the existing laws and introducing new laws or even in the forms of changes to the structures of the built environment. However, this further implies the importance of attracting those who use such smaller vehicles to the public transport system by extensively focusing on its quality. As further discussed in this paper, the rising number of motorbikes could be a significant determinant of traffic congestion in the future, which needs to be systematically studied. Hence we propose to use agent-based modeling and simulation to build a predictive model to investigate whether this rise of motorbikes ends up creating motorbike swarms in cities creating unexpected results.

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Chapter 4
Information Technology and Finance

Hiroshi Takahashi

Abstract Recent developed information technology has had a great impact on our society and research activities. Finance is one of the areas which enjoy the fruits of information technology. This article discusses the influence of information technology on business and finance. One of the promising applications of information technology in finance is agent-based modeling. This article looks to offer an overview of the kind of research agent-based models are enabling.

Keywords Finance · Information technology · Agent-based model · Asset pricing · Artificial intelligence

4.1 Introduction

In recent years, interest in information technology has exploded. In particular, research using deep learning, a machine learning method, has produced numerous remarkable results. Deep learning has made huge leaps in areas such as image recognition and natural language processing. Research has been actively conducted in the academic and practical fields. The impact of information technology on business enterprises and academic analysis cannot be overstated. For example, even a little while ago, self-driving cars were regarded as the potential invention of a far, distant future, but now research and development is currently underway with a view to putting it into practical use. Even in the financial field, business and research utilizing information technology is gathering great attention. In this article, I discuss the influence of information technologies on business and social sciences and illustrate several research examples which utilize information technologies.

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The next section outlines the influence of information technology on business and financial research. Then, Sect. 4.3 provides an overview of some analyses from agent-based models, as an application example of financial information technologies. Section 4.4 summarizes this article.

4.2 Influence of Information Technology

4.2.1 On Occupation

In connection with the development of information technology, there is a growing debate about the possibility of AI systems and robots replacing a wide range of professions.

For example, Frey and Osborne (2017) discuss the possibility of replacing numerous occupations with computers in the future (Frey and Osborne 2017). Frey and Osborne (2017) show the results of summarizing the probability that each occupation will be replaced by a computer for each type of occupation. In the analysis, Frey and Osborne (2017) analyze 702 occupations. For example, in the financial field, a credit analyst has a ranking of 677 with the probability that this job will be replaced by automation of 98% (Frey and Osborne 2017). The profession of loan officer has a similar ranking. The social concerns about the influence of information technology are high, and various discussions will continue in the future (Takahashi 2017).

4.2.2 On Corporations

What role does information technology play in companies? For example, information necessary for corporate activities can be acquired efficiently via the Internet, and geographically separated parties can exchange information in a timely manner via e-mail, WEB conference system, and the like. A company's system is built on the premise of such a function. In that sense, it can be seen that information technology is influencing the way people behave.

Due to the progress of information technology, the amount of information that individuals can handle has also dramatically increased. The increase in the amount of information gathered by individuals will also affect the role and the impact of those individuals. For example, CEOs expected to play a central role in corporate decision-making can make decisions based on a lot of information. Depending on such changes in the environment, organizational behaviors may change. In that sense, information technology has aspects that promote the efficiency of corporate activities, as well as aspects that change the role of real organizations and individuals (Fig. 4.1). Information technology plays a significant role in business.

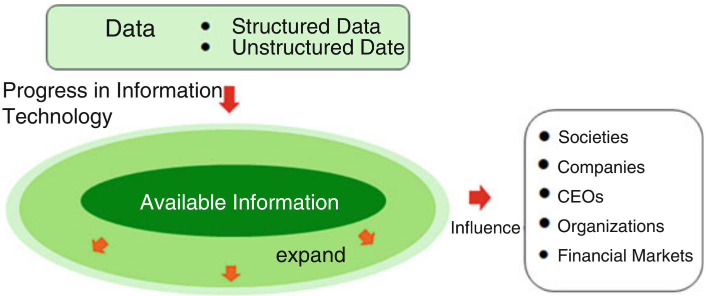

Fig. 4.1 Influence of information technology

4.2.3 On Organizations

A real corporate organization may take various forms (such as a hierarchical organization or a flattened organization) reflecting the business environments of each company. Even in the finance field, there are many discussions about corporate organization from the view point of information flow, for example. Some of this information is transmitted and understood with ease, some of it less so. For example, Stein (2002) points out the possibility that the structure of an appropriate corporate organization differs according to the ease with which companies handle information (Stein 2002). Also, Stein (2003) discusses how a CEO's ability will have a major impact on business's activities. For example, if the CEO's expertise is high, and appropriate evaluation is possible, the person in charge who reports to the CEO will have an incentive to produce appropriate materials (Stein 2003).

In other words, the ability of the CEO may affect the quality of information circulated in the company. Furthermore, Guadalupe et al. (2013) point out that the structure of the management of a US company has changed dramatically since the mid-1980s and managers reporting directly to the CEO have doubled (Guadalupe et al. 2013). Guadalupe et al. (2013) point out that the development of information technology could have an impact on the structure of corporate organizations (Guadalupe et al. 2013).

The business environment surrounding enterprises keeps changing over time, including related institutions and regulations, the situation of competitors, the quality and cost of available information technology, and so on. From a certain point of view, it is natural that companies will continue to change their systems, business activities, decision-making processes, organizational methods, and the role of management while being influenced by changes in their business environment. Also, when looking at a large number of companies, it is clear that, while companies may have any number of things in common, there remain enough differences to mean that each company is unique in how it might optimize its performance. The responsibility for optimizing a company's performance lies, ultimately, with the company itself.

4.2.4 On Financial Research

What is the impact of developed information technology on finance research? Essentially there are two kinds of financial research: theoretical and empirical. There is a lot of interaction between the two. Analysis based on numerical data has mainly been carried out by empirical research. The development of information technology which enables us to analyze various kinds of data, including text data, could make a significant contribution to empirical research in finance.

For example, the news delivered through electronic terminals to fund managers belonging to institutional investors is near-instantaneous and is one of the most valuable information sources for investment decision-makings. There is a huge quantity of news articles. Some of them are very timely, dealing with the immediate future. Other articles address topics further in the future. Other news concerns itself with the past. Yet all of those kinds of news articles have an interactive relationship with asset prices. News articles are categorized into textual data, which is relatively difficult to analyze when compared to numerical data. With the progress of information technology in recent years, detailed analysis can be performed through a neural language model, such as deep learning. One of our recent pieces of research analyzed textual data using a neural language model and uncovered a mutual relationship between news articles and asset price fluctuations (Goshima and Takahashi 2016). Other research has attempted to analyze textual data written in several languages and show the relationship between news articles and asset price fluctuations using high-frequency trading data in Korean markets (Yoon et al. 2017).

Although research on the relationship between information and prices is a major concern in asset pricing theory, there is a possibility that more accurate analysis could be performed through incorporating cutting-edge information technology. For example, in corporate activities, the relationship between companies is also an important factor. Network analysis could be applied to uncover the relationship of companies (Raddant and Takahashi 2016). By utilizing a new method in information technology, it may be possible to acquire new knowledge that has been difficult to find until now (Jotaki et al. 2017).

4.3 Application to Financial Analysis: Agent-Based Model

Computer simulation can also be used to analyze the impact of information flow. For example, it is possible to construct a financial market on a computer and analyze the influence of information on asset pricing through computational experiments. Such a method is called an agent-based model (ABM). Agent-based models are effective in analyzing a multi-agent system where a great number of agents acting autonomously gather together. A great deal of prominent research relating to social sciences has been carried out using agent-based models (Epstein and Axtell 1996; Axelrod 1997; Lux and Marchesi 1999).

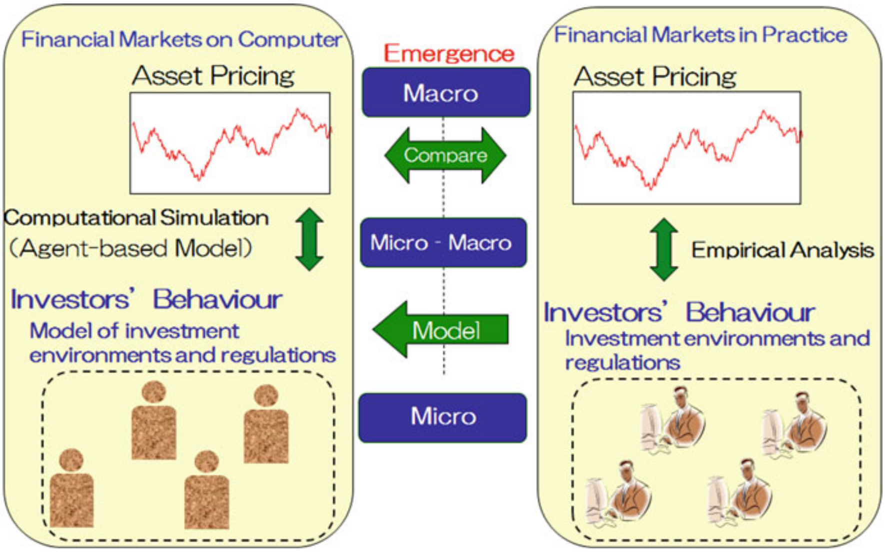

Fig. 4.2 Financial markets and agent-based modeling

Figure 4.2 shows the relationship between practical financial markets and agent-based model (financial markets on computers).

As an analysis using an agent-based model, various kinds of research, such as analysis focusing on decision-making bias in behavioral finance (Takahashi and Terano 2003, 2007), analysis focusing on investment constraints (Takahashi 2012a; Kikuchi et al. 2017), analysis focusing on financial risk management (Takahashi 2013), analysis on market efficiency (Takahashi et al. 2007; Takahashi 2010), and analysis incorporating real human decision-making through business games (Yamashita et al. 2010), have been carried out.

In this section, we show an example of financial research which focuses on determining the effectiveness of a particular investment method (fundamental index) through an agent-based model (Takahashi 2012b).

4.3.1 Model

A computational financial simulator of financial markets involving 1000 investors was used as the agent-based model in this research (Takahashi and Terano 2003). Shares and risk-free assets were the two types of assets used, along with the possible transaction methods. Several types of investors exist in the market, each undertaking transactions based on their own stock evaluations. This market was composed of three major stages: (1) the generation of corporate earnings, (2) the formation of investor forecasts, and (3) the setting of transaction prices. The market advances through repetition of these stages. The following sections describe negotiable transaction assets, modeling of investor behavior, setting of transaction prices, and the rule of natural selection (Goldberg 1989).

4.3.2 Outline of Experimental Results: Effectiveness of Fundamental Index

In this section, we analyze the effectiveness of a fundamental index, which is a relatively new investment method in the asset management business.[1]

Figures 4.3, 4.4, and 4.5 show the transition of market prices, trading volume, and the number of investors, where there are the same numbers of five types of investors (Table 4.1: Type 1–5), including smart beta investors. These results suggest that the market situation can be divided into three periods, as follows: (1) the period when the numbers of both fundamentalists and smart beta investors increase; (2) the period when the number of fundamentalists decreases; (3) the period when all investors employ smart beta strategies. These results suggest the effectiveness of smart beta strategies. For a detailed analysis of these results, see Takahashi (2012b).

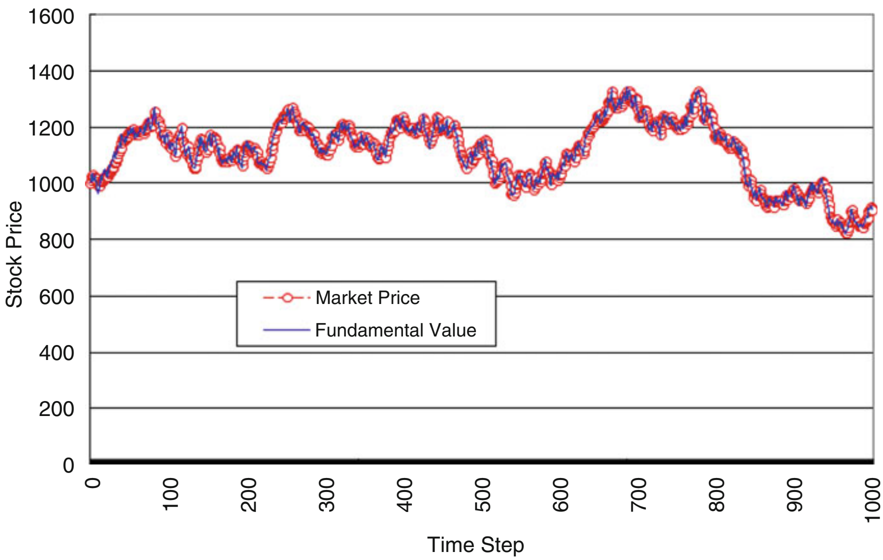

Fig. 4.3 Transition of stock prices

[1]In this analysis, we have conducted a new computational experiment based on the conditions in Takahashi (2012b).

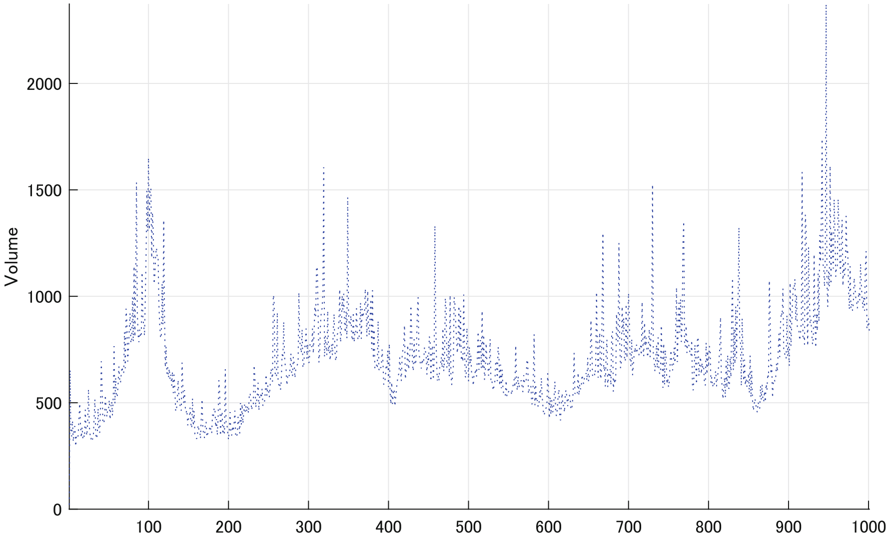

Fig. 4.4 Transition of trading volume

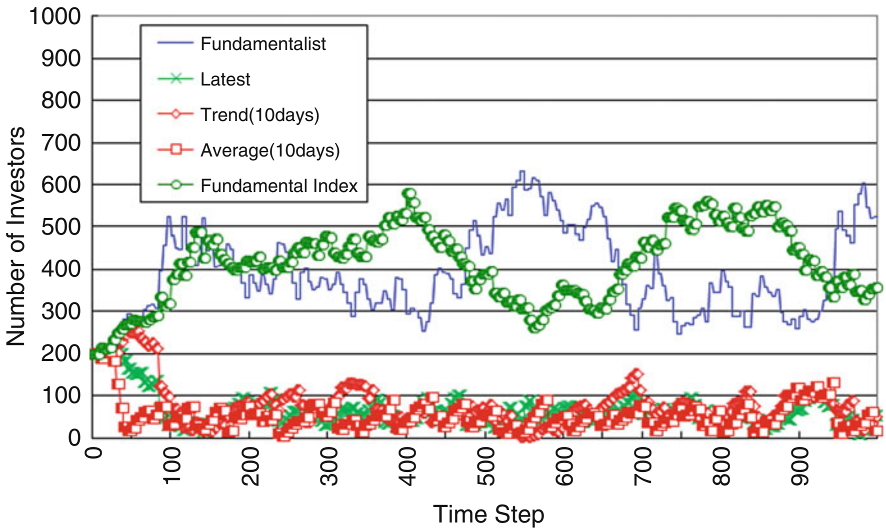

Fig. 4.5 Transition of number of investors

The research presented here is a good example of information technology being applied to financial analysis. This kind of agent-based modeling can make a significant contribution to both academic and practical discussions.

Table 4.1 List of investors type

No.	Investor type
1	Fundamentalist
2	Forecasting by latest price
3	Forecasting by trend
4	Forecasting by past average
5	Fundamental index

4.4 Conclusion

Progress in information technology will have an impact on many levels of the business world: corporate organization, the role of management, and analytical research methods will all be affected. Markets produce and consume huge amounts of data. Developments in information technology will inevitably affect how this information is produced, consumed, and, perhaps most importantly, analyzed. Since the financial world, through markets and corporate activity, shapes the real world, developments in information technology and how they impact business are of great interest. There are various avenues of research to be pursued in the future.

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Chapter 5
Two Phase Transitions in the Adaptive Voter Model Based on the Homophily Principle

Takashi Ishikawa

Abstract Dynamics on and of networks are two basic processes that drive coevolving networks such as online social networks. The paper investigates the mechanism of coevolving networks using a generalized adaptive voter model based on related work and the homophily principle which is known as a driving mechanism to form community structure in social networks. The proposed model has mechanisms for dynamics on and of coevolving networks, which are node state change via social interactions and link rewiring based on homophily. The numerical simulation of the proposed model reveals that there exist two phase transitions for the parameters adaptability and homophily. This observation implies that the nature of the homophily principle lies in the adaptive mechanism in the proposed model.

Keywords Adaptive voter model · Coevolving networks · Self-organization · Homophily principle · Online social networks

5.1 Introduction

An important issue in the research of complex networks is to clarify why and how the peculiar structures of complex networks emerge. This issue is named self-organization of complex networks in general, and many findings are acquired in the researches of such as coevolving networks (Fernando 2007) and adaptive networks (Braha and Bar-Yam 2006; Braha and Bar-Yam 2009; Gross and Sayama 2009; Hill and Braha 2010) in which node states and network topology coevolve in time. In the field of social networks, the homophily principle is known as a fundamental mechanism that drives the emergence of community structure in the social networks (McPherson et al. 2001). The principle characterizes the tendency of people to connect with more similar persons. It could explain the emergence of community

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structure in social networks by the cohesive property of human, but why multiple communities that are dynamical stable in time emerge is not sufficiently explained in the previous researches.

The research aims to deduce the self-organization mechanism for the emergence of community structure in complex networks by formalizing network dynamics based on the homophily principle. The goal is to express the homophily principle in a mathematical model of network evolution, contrasting to the qualitative expression in social science. In order to achieve the goal, the research employs an approach of statistical physics (Kadanoff 2000; Sen and Chakrabarti 2013), which explain the self-organization phenomena with the interaction between many elements of a system. For this purpose the author analyzes the conditions by which community structure emerges as a result of the homophily principle by using the adaptive voter model that is one of the simple models for the emergence of community structure in dynamic networks (Holme and Newman 2006).

The paper organized as follows. Section 5.2 introduces the previous researches on the adaptive voter models, and Sect. 5.3 discusses the homophily principle as a self-organizing mechanism of dynamic networks. Then Sect. 5.4 describes a generalized adaptive voter model based on the homophily principle, which unifies some of the adaptive voter models in the related work. Section 5.5 describes the method and results of the numerical simulation to analyze the conditions with which community structure emerges. Finally Sect. 5.6 concludes the paper and states the future works.

5.2 Related Work

Vazquez (Vazquez 2013) reviews recent researches on the dynamics of opinion formation in a society. Voter model and threshold model are most studied to investigate the competition between two or more equivalent opinions. In voter models, individuals adopt the opinion of random partners, while in threshold models, an opinion update occurs only when the number of partners with the opposite opinion overcomes a given threshold value. Recent researches on coevolving or adaptive networks investigate how the coupled evolution of opinions and network induces new macroscopic patterns, such as stable or metastable coexistence of opinions, or fragmentation of the network in communities. The result is that the likelihood of each of these outcomes depends on the relative speed of the opinion spreading and network adaptation processes. In the way, consensus of a single opinion is usually achieved when opinions spread faster than the evolution of the network, while for fast adaptation the network splits into static or sometimes dynamic communities of same-opinion individuals.

Vazquez et al. (2008) studies a coevolving voter model of interacting binary state nodes, in which individuals may select their interaction partners according to their states. The state dynamics consists of nodes copying the state of random neighbor, while the network dynamics results from nodes dropping their links with opposite-state neighbors and creating new links with randomly selected same-state nodes. The coevolution mechanism on the voter model induces a fragmentation transition that is a consequence of the competition between the copying and rewiring dynamics. In the connected active phase, the system falls in a dynamical steady state with finite fraction of active links that connect nodes of different states. The slow and permanent rewiring of these links keeps the network evolving and connected until by a finite-size fluctuation the system reaches the fully ordered state (all nodes in the same state) and freezes in a single component. In the frozen phase, the fast rewiring dynamics quickly leads to the fragmentation of the network into components, before the system becomes fully ordered.

González-Avella et al. (2014) proposes a general framework for study of adaptive rewiring processes that allows for understanding of the emergence, as well as the persistence of communities in a voter-like model. The framework characterizes an adaptive rewiring process in terms of two actions: disconnection and connection between nodes, in which rewiring the links between nodes takes into account the node state. The collective behavior of the system is investigated on the space of parameters characterizing the two actions. Two main phases are found on this space: a phase where most nodes form a large connected network and a fragmented phase formed by small disconnected components. Between these two phases, there exists a region of parameters where a community structure emerges and diverse states coexist on one connected networks. To characterize the mechanism for the two actions, the framework uses a parameter $d \in [0, 1]$ representing the probability that two nodes in identical states become disconnected and another parameter $r \in [0, 1]$ representing the probability that two nodes in identical states become connected. An adaptive rewiring process can be characterized by a pair (d, r) in the parameter space. To characterize the collective behavior of the system, the framework employs two order parameters, the normalized average size of the largest connected component S and the modularity change $\Delta Q \equiv Q(t) - Q(0)$, where modularity $Q(t)$ at time t is defined as the fraction of inactive links that connect nodes of identical states. Figure 5.1 shows the resulting phase diagram on the (d, r) plane in absence of node dynamics: (i) phase I (connected network), comprising two distinct dynamical behaviors of the network, I_a (stationary random topology) and I_b (emergence of community structure), and (ii) phase II (fragmented network).

Gross and Blasius (2008) review researches on adaptive networks that appear in many areas of researches, such as social science, biology, ecology, epidemiology, game theory, genetics, neural and immune systems, and communication. They pointed out all adaptive networks share some common features at the macroscopic level, such as self-organization to critical behavior, formation of complex topologies, more complex macroscopic behavior than static networks, and the emergence of special nodes from a homogeneous population.

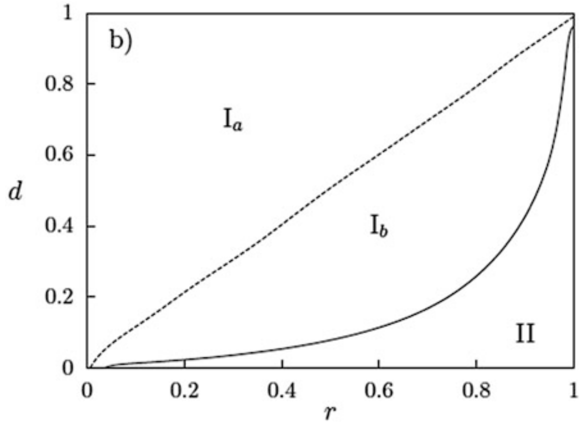


Fig. 5.1 Phase diagram in González-Avella et al. (2014)

5.3 Homophily Principle

The fact that similarity breeds connections, the principle of homophily, has been well-studied in existing sociology literature, and several studies have observed this phenomenon by conducting surveys on human subjects (Bisgin et al. 2012). These studies have concluded that new ties are formed between similar individuals. This phenomenon has been used to explain several sociopsychological concepts such as segregation, community development, social mobility, etc. It is observed that real social networks tend to divide into groups or communities of like-minded individuals (McPherson et al. 2001).

An obvious question to ask is whether individuals become like-minded because they are connected via the network or whether they form network connections because they are like-minded (Holme and Newman 2006). Both situations have been modeled using physics-style methods, the first with opinion formation models and the second with models of assortative mixing or homophily. In the real world, both mechanisms may be in effect at once the network changing in response to opinions and opinions change in response to the network change (Zimmermann et al. 2004). In the simplest case, the dynamics of the network might be independent of the spreading phenomena, but in reality both dynamics are coupled (Vazquez 2013). On one hand, individual's decisions are influenced by their neighbors through the mechanism of social pressure, and on the other hand, individuals have tendency to continuously change their connections, forming new ties with similar others (homophily) or with diverse groups (heterophily). This creates a feedback loop between the states of the nodes and the topology of the interaction network, giving rise to a very rich and complex dynamics. Networks that exhibit such properties are called adaptive or coevolving networks (Gross and Blasius 2008). Experimental evidence of this coevolutionary dynamics can be found in Lazer (2001).

5.4 Generalized Adaptive Voter Model

In order to investigate the self-organizing properties of the adaptive voter model in general, the paper proposes a generalized adaptive voter model based on the previous models in related work described in Sect. 5.2. The network of the model is basically a simple undirected graph consisting N nodes. Each node has one of G opinions as its state. In order to simplify the model, the mean degree k of the network is constant in time despite the rewiring process. The two processes of node state change and link rewiring are modeled as a stochastic process independent with each other. The state change corresponds to the induced homophily, and the link rewiring corresponds to the preference homophily in the homophily principle (Kossinets and Watts 2009).

The algorithm describing the dynamics of the model iterates the following three steps starting from a given network configuration, which is usually a random network:

1. Choose a node i at random.
2. Do state change of the node with probability p.
3. Do link rewiring for the node with probability q.

In Step 2, choose a node $j \in v_i$ at random, where v_i represents a set of neighbors of node i, and if the states of i and j are different, then change the state of i to the state of j, otherwise do nothing. In Step 3, choose a node $k \in v_i$ at random, where k may equal to j; if the states of k and i are different, then remove the link between k and i with probability d, and at the same time make a link of i to a node l with the same state of i, with rewiring probability r; otherwise make a link of i to a node l' with the different state from i, with the complementary probability $1 - r$. This link rewiring is done only when all these conditions are satisfied. The value $d = r = 0.5$ represents random rewiring, and the values $d = 0$ and $r = 1$ represent the strongest preferential homophily. The stochastic processes of the model are completely designated with these four parameters p, q, d, and r.

5.5 Simulation

5.5.1 *Objective*

The objective of the simulation is to confirm the existence of two phase transitions in the adaptive voter model based on the homophily principle described in the last section. In this context, the phenomenon of phase transition is defined as that there exist at least one region of a certain model parameter, in which some order parameter for the process on the model stays same level as a phase (Kadanoff 2000). Therefore, we require order parameters to describe phase transition and find model parameters to cause phase transition in the order parameter. In literature we know global consensus in the simple voter model as a phase transition where the fraction of nodes with an opinion reaches maximum in accordance with the increase of the probability of state change in onetime step. Furthermore recent research (Böhme and Gross 2012) shows that there exists so-called fragmentation transition in some of the adaptive voter models, where the size of the largest component tends to small in accordance with increase of the ratio of the link rewiring probability to the state change probability. From these findings, we choose the size of the largest component S and the size of the largest community M as the order parameters to describe global consensus and fragmentation transition, respectively, where these parameters are normalized with the number of nodes N.

5.5.2 Method

We have four parameters in the generalized adaptive voter model, which are the probability of state change p, the probability of link rewiring q, the probability of disconnection for the inactive link d, and the probability of rewiring to same opinion r. Since global consensus depends only on the ratio of p and q from the findings in related work, we define *adaptiveness* a as a reduced model parameter which is the ratio of q to p, which represents the ability of the network change to adapt the state change of nodes. Also we define *homophily* h as another reduced model parameter that is the difference between r and d, which represents the tendency to rewire to the node of the same opinion known as the homophily principle. Table 5.1 specifies three order parameters and the model parameters in the simulation including the number of nodes N, mean degree k, and the number of opinions G. We set these model parameters to the values similar to that of the related work in order to compare the results. Since the dynamics on and of the model is stochastic, we iterate simulation ten times for a similar parameter settings and conduct each simulation for sufficient longtime steps. We measure order parameters by averaging the values in the last 100 intervals of 100 time steps for 1 sequence of time steps and further average the mean values for 10 iterations of 1,000,000 time steps.

5.5.3 Network Evolution

The two order parameters S and M evolve in time, starting from an initial random network, as the plots in NetLogo interface shown in Fig. 5.2, where the legends maxcmp (red line) for S and maxcom (blue line) for M. The plots also show modularity m (modular; green line) and clustering coefficient C (cluster; yellow line) as network properties representing community structure. These order parameters and properties fluctuate in time, but they are almost stable for long period in case of no global consensus and fragmentation. The right-hand graph in Fig. 5.2 shows community structure of the network generated by the model algorithm for a

Table 5.1 Model parameters

Parameter	Description	Value(s)
S	The normalized average size of the largest connected component	Order parameters
M	The normalized average size of the largest community	
ΔQ	The modularity change $Q(t) - Q(0)$	
N	The number of nodes	200
k	Mean degree of the network	4
G	The number of opinions	20
p	The probability of state change	$0 \sim 1.0$
q	The probability of link rewiring	$0 \sim 1.0$
d	The probability of inactive link disconnection	$0 \sim 1.0$
r	The probability of inactive link connection	$0 \sim 1.0$
a	Adaptiveness q / p	$0.001 \sim 1000$
h	Homophily $r - d$	$-1.0 \sim 1.0$

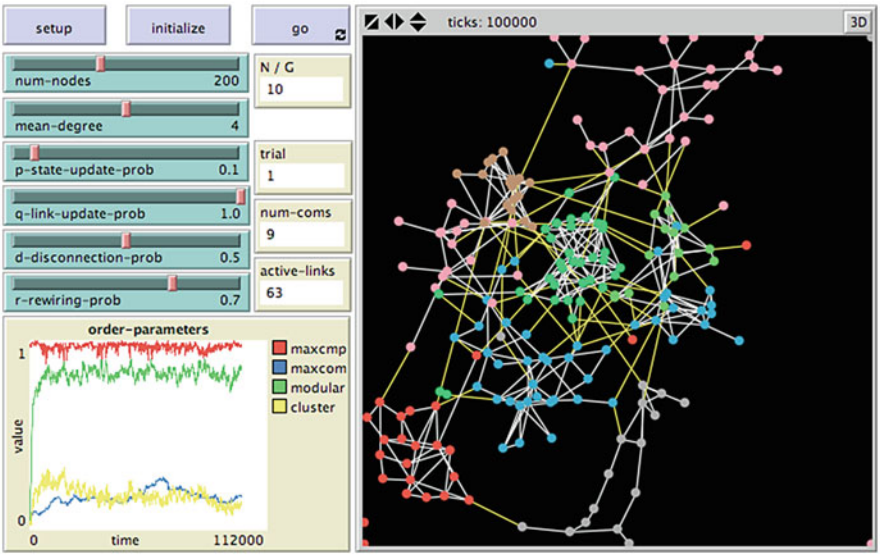


Fig. 5.2 Network evolution in the simulation

typical parameter setting. The size of each community consisting nodes with same opinion fluctuates in time, but some of the communities persist in time according to the parameter setting. For the case of Fig. 5.2, 9 communities persist and 11 communities disappear.

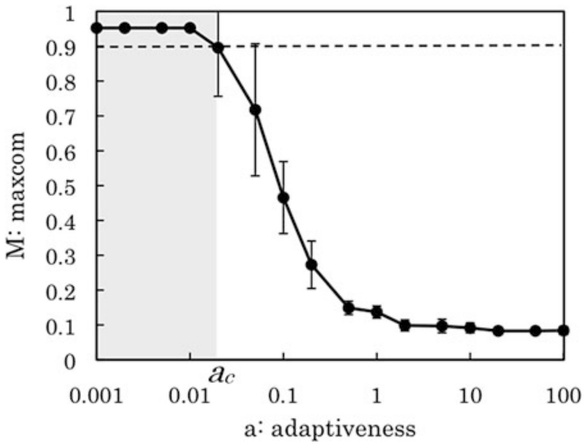


Fig. 5.3 Global consensus transition

5.5.4 Global Consensus

The first kind of phase transition in the model appears in the size of the largest community M as the response to adaptiveness a. Figure 5.3 depicts a typical global consensus transition at the critical point $a_c \sim 0.01$ for $h = r - d = 0$, $d = 0$, $r = 1$, $q = 0.001$, where the error bar represents standard deviation of the data. In the region below a_c, almost of nodes (>0.9) belongs to the same community whose opinion is stochastically determined. In the other region over a_c, M gradually decreases as a increases. The value of a_c is constant for all range of $h = -1.0 \sim 1.0$. This observation implies the global consensus transition in the model is independent of homophily $h = r - d$.

5.5.5 Fragmentation Transition

The second kind of phase transition appears in the size of the largest component S as the response to homophily h. Figure 5.4 depicts a typical fragmentation transition at the critical point $h_c \sim 0.5$, for $a = 10$, $d = 0.1$. In the region over h_c, the network splits into small fragments whose size is less than 0.4, which is significantly smaller than half of the population. In the other region below h_c, S gradually increases as h decreases. The value of h_c is not constant, which depends on a as described in the next subsection. This observation is specific to the generalized adaptive voter model in this paper, which clarifies the nature of homophily in the adaptive voter model.

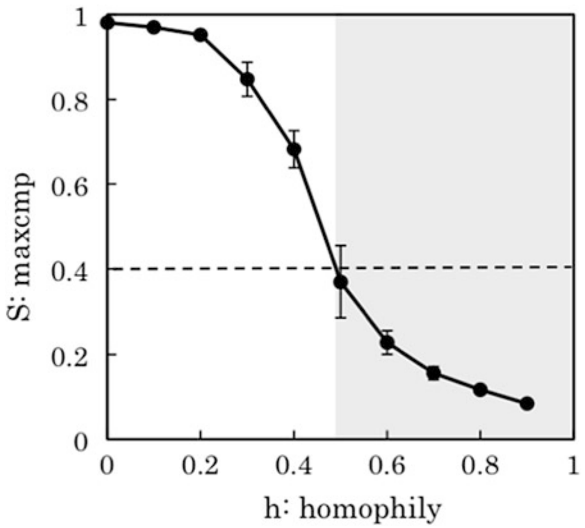


Fig. 5.4 Fragmentation transition

5.5.6 Phase Diagram

Figure 5.5 shows the phase diagram of the generalized adaptive voter model based on the observation of a_c and h_c for the wide range of model parameters. There exist two phase transitions in the diagram, which form global consensus phase and fragmentation phase. Between these two phases, the network consists of some communities that are connected into one large component. This observation implies that there exists the emergence of community structure in the adaptive voter model, which are also reported in the related work. The number of communities Nc normalized with N depends on a and h as shown in Fig. 5.6. The Nc in the model depends mainly on a and slightly on h.

5.5.7 Modularity Change

The main result of the simulation is the modularity change ΔQ in the model varies in complex manner as a result of the feedback effect between state change and link rewiring as shown in Fig. 5.7. Specifically the fragmentation transition in the model appears nonlinearly depending on a and h. This observation clarifies the complex nature of homophily in the adaptive voter model.

Figure 5.8 shows the dependency of modularity on the probability r of inactive connection in rewiring process for the case, $a = q / p = 10$, $d = 0.5$. When $r = 0$ (complete active connection) and $d = 0.5$ (random disconnection), the modularity change ΔQ even after sufficiently long time steps nearly equals to zero, which means the network remains in the initial random network. On the other hand

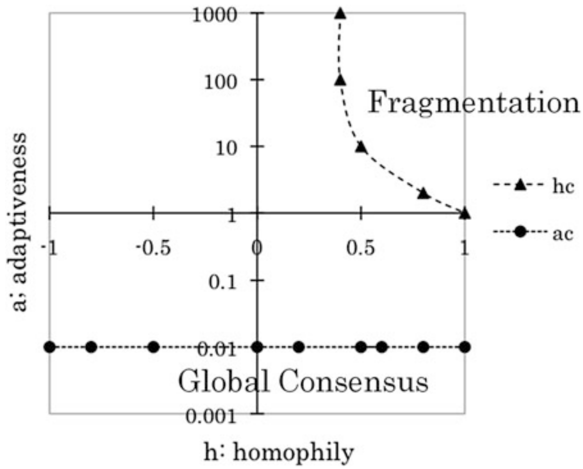


Fig. 5.5 Phase diagram of the proposed model

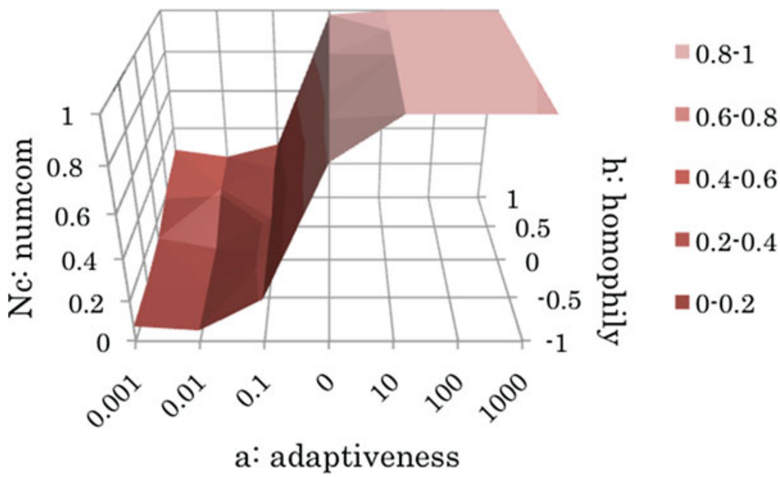


Fig. 5.6 The number of communities *Nc* vs. *a* and *h*

for $r = 1.0$ (complete inactive connection), network becomes almost fragmented consisting one or more disconnected communities. This observation implies that large homophily ($r > 0.5$) causes fragmentation transition for large adaptiveness ($a > 1$). This result reveals the intrinsic nature of the homophily principle in the adaptive voter model.

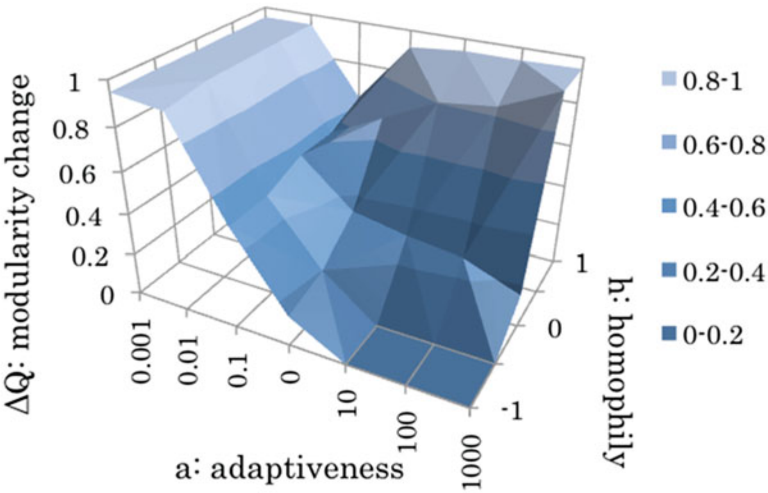
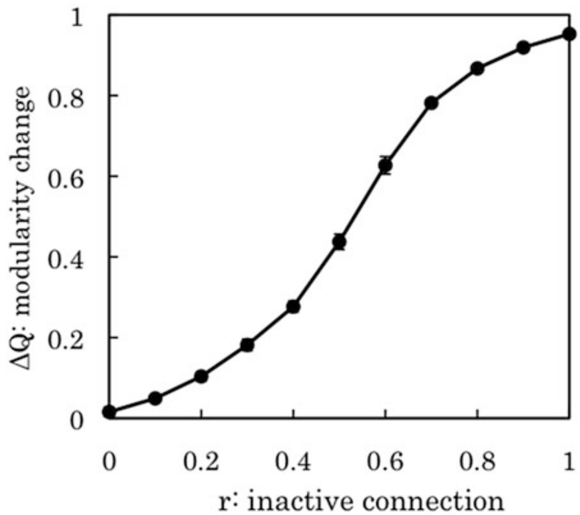


Fig. 5.7 Modularity change ΔQ vs. a and h

Fig. 5.8 Modularity change ΔQ vs. prob. of inactive connection r



5.6 Conclusion

The results of the simulation show the existence of two phase transitions in the adaptive voter model based on the homophily principle. One kind of the phase transitions is the global consensus transition where almost of nodes have the same opinion after sufficiently longtime steps, and this transition exists independent of homophily for small adaptiveness which corresponds to less link rewiring. The other kind of phase transitions is the fragmentation transition where the network splits into a number of disconnected components in the steady state of network evolution, and the transition exists for large adaptiveness and large homophily. These findings are only first clarified by the generalized adaptive voter model proposed in the paper. However, there remain several issues to investigate further, for example, the effect of diversity of individual adaptiveness and homophily and the dependency of phase transitions to the number of nodes. These issues will be clarified in the future work.

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Chapter 6
Sensitivity Analysis in a Bayesian Network for Modeling an Agent

Yoko Ishino

Abstract Agent-based social simulation (ABSS) has become a popular method for simulating and visualizing a phenomenon while making it possible to decipher the system's dynamism. When a large amount of data is used for an agent's behavior, such as a questionnaire survey, a Bayesian network is often the preferred method for modeling an agent. Based on the data, a Bayesian network is used in ABSS. However, it is very difficult to learn the accurate structure of a Bayesian network from the raw data because there exist many variables and the search space is too wide. This study proposes a new method for obtaining an appropriate structure for a Bayesian network by using sensitivity analysis in a stepwise fashion. This method enables us to find a feature subset, which is good to explain objective variables without reducing the accuracy. A simple Bayesian network structure that maintains accuracy while indicating an agent's behavior provides ABSS users with an intuitive understanding of the behavioral principle of an agent. To illustrate the effectiveness of the proposed method, data from a questionnaire survey about healthcare electronics was used.

6.1 Introduction

The Bayesian network technique has recently become popular because it is suitable for modeling an agent's behavior in agent-based social simulation (ABSS), when a large amount of data is used (Matsumoto et al. 2017). A Bayesian network is a graphical probabilistic model. This model can be used as a modeling technique and a reasoning engine for a marketing forecast system (Tsukasa et al. 2011) or a

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decision support system (Constantinou et al. 2015). The advantage of a Bayesian network is that it can simultaneously handle multiple objective variables (Cai et al. 2010).

However, it is intrinsically very difficult to learn the accurate structure of a Bayesian network from the data when multiple variables exist because the search space becomes too wide. Currently, heuristics, such as a greedy algorithm, hill-climbing algorithm, and/or a genetic algorithm, are used to search a Bayesian network structure (Pelikan et al. 2002). In addition to this problem, the Bayesian network structure requirements also vary depending on its intended use.

When accuracy is the first priority in data analysis, as many variables as possible are used to develop a Bayesian network that expresses the problems faced by people. In this case, we do not need to understand the network structure, which is the causal relationship between variables. In contrast, if an expert in a field, such as a marketer, needs to decide some concrete actions based on the results of Bayesian networks, he or she must interpret the results. Therefore, an appropriate number of variables for Bayesian networks should be selected in advance. Otherwise, the network configuration is generally too complicated to understand the causal relationship between the variables when this configuration is derived from data.

Thus, although Bayesian networks can be a solution to agent modeling, the feature selection problem remains. Consumer survey data often contain redundant variables (i.e., features). These variables can provide misleading correlations between the dependent and independent variables. Feature selection involves choosing a small subset of relevant dimensions while retaining the explanatory ability. Successful feature selection provides the following benefits:

1. Data interpretation becomes more tractable.
2. The risk of overfitting is largely avoided.
3. Noisy features are eliminated.

Feature selection addresses the question of which features should be retained or discarded.

This study proposes a new method for obtaining an appropriate structure for a Bayesian network by using sensitivity analysis in a stepwise fashion. This method enables us to find a feature subset, which is good to explain (or classify) objective variables without reducing accuracy. The effectiveness of the proposed method was illustrated using data from a questionnaire survey about healthcare electronics. We selected two devices: a blood-pressure monitor and an activity monitor.

The remainder of this paper is organized as follows. Section 6.2 introduces related studies. Section 6.3 describes the proposed method in detail. Section 6.4 presents the experimental results obtained by applying the proposed method to the real questionnaire data about healthcare home electronics. Finally, Sect. 6.5 presents the conclusions of this study.

6.2 Related Work

6.2.1 Bayesian Network

A Bayesian network graphically models probabilistic relationships among a set of variables. Over the last decade, Bayesian networks have become a popular representation for encoding uncertain expert knowledge in expert systems (Heckerman et al. 1995). Recently, researchers have developed methods for deriving Bayesian networks from data (Friedman et al. 1997, 1999; Jensen 2001; Jordan 2004; Lauritzen 1996; Holmes and Jain 2008). When used in conjunction with statistical techniques, a Bayesian network provides several benefits in the analysis of data. The greatest advantage is that a Bayesian network can be used to determine causal relationships agnostically from the data; hence, it can be used to understand a problem domain and to predict the consequences of intervention.

A Bayesian network consists of nodes, edges, and conditional probability tables (CPT). Nodes represent events or states, and edges represent conditional dependencies. In this paper, nodes represent discrete variables, which are questionnaire items related to consumers' attitudes and behaviors. These variables have causal relationships; therefore, the edges in this paper are directed arrows. In this paper, we consider only a directed acyclic graph; therefore, it is mathematically manageable.

A Bayesian network can represent nonlinear covariation between features and does not assume a Gaussian distribution of variables because the relationship between the features is given in the CPT. The structure of the model can be learned from the data based on information criteria, such as Akaike's Information Criterion (AIC) and Minimum Description Length (MDL) (Chen et al. 2008). In addition, prior knowledge of a model designer can be embedded in the model in advance in the form of model constraints. The Bayesian network structure obtained from the learning data enables us to compute the posterior distribution of variables (states) when the independent variables (the evidence variables) are observed. In this process (which is called probabilistic inference), researchers have proposed certain efficient computational algorithms, such as the loopy belief propagation (Weiss 2000; Mooij and Kappen 2007). These features are very convenient; therefore, Bayesian networks are now being applied to re-create complex human behaviors in marketing (Blodgett and Anderson 2000).

6.2.2 Feature Selection

Feature selection is a process used to select a subset of original features; it is an important and frequently used technique in data preprocessing (Blum and Langley 1997; Liu and Motoda 1998). Finding an optimal feature subset is usually intractable (Liu and Motoda 1998), and the feature selection problem belongs to the class of NP-hard problems (Blum and Rivest 1992). When the number of features is large, the selection process cannot be solved exactly within an acceptable duration of computation time. Therefore, heuristic optimization algorithms have evolved to solve large-scale combinatorial problems. Over the past four decades, many studies on feature selection have been carried out. Feature selection has a wide field of application in physical therapy science, pharmaceutical sciences, and biology (Khair et al. 2015; Sierra et al. 2001; Kawasaki et al. 2014; Cho et al. 2008).

Many available feature selection algorithms are often categorized into three modalities: wrapper, filter, and embedded methods (Guyon and Elisseeff 2003). In the wrapper approach, feature selection "wraps" a learning algorithm as a black box. The algorithm is then applied to the feature subsets using the ranking of the subset features by their predictive power (Yang and Honavar 1998). Greedy wrapper methods use less computer time than other wrapper approaches. Backward stepwise elimination (Cotter et al. 2001) and forward stepwise selection (Colak and Isik 2003) are the two most commonly used wrapper methods that use a greedy hill-climbing search strategy.

In filter approaches, features are scored and ranked based on certain statistical criteria. Then, we select the features with highest ranking values. Frequently used filter statistics include the t-test (Hua et al. 2008), the chi-square test (Jin et al. 2006), mutual information (Peng et al. 2005), and Pearson's correlation coefficients (Biesiada and Duch 2007). Filter methods are quick, but they are not robust enough against interactions among features and feature redundancies.

6.3 Proposed Method

The purpose of this study is to determine a subset of features (explanatory variables) that provide useful knowledge leading to concrete action while simultaneously obtaining high classification performance against multiple objective variables. The proposed method simplifies a Bayesian network by using probabilistic inference for sensitivity analysis. When the Bayesian network structure is simplified and accuracy is maintained for indicating an agent's behavior, it gives ABSS users an intuitive understanding of the behavioral principle of an agent.

When ABSS employs a Bayesian network as an agent's model, the problem begins by searching the network structure based on data. If we try to search the network structure without setting any constraints, the search space often becomes too wide to obtain an appropriate structure. Even when setting some reasonable constraints, the search space still remains wide; therefore, heuristics, such as a greedy algorithm, hill-climbing algorithm, and/or a genetic algorithm, are used for searching (Pelikan et al. 2002). Usually, we try to extract knowledge that a domain expert (or analyst) possesses regarding the topics. Then, we try to translate it into the relationship constraints between variables.

However, it is very difficult to make any definite conclusion before analyzing data. Therefore, this study focused on generating a few possible hypotheses instead of using definite knowledge. Then, the generated hypotheses were translated into the constraints (relationships among variables) and used for searching the influential variables.

The procedure of the proposed approach is as follows:

Step 1. The objective variables are set. Usually, there are more than one objective variable.

Step 2. A domain expert (or analyst) proposes hypotheses for each objective variable.

Step 3. Based on each hypothesis, the expert qualifies the candidates of the explanatory variables that are thought to directly affect an objective variable.

Step 4. For each objective variable, the search for partial structures is performed as follows:

- (a) When the number of candidate variables does not exceed the threshold value, a partial structure of a whole Bayesian network is learned from data.
- (b) When the number of candidate variables exceeds the threshold value:
  - (i) The candidate variables are divided into several groups.
  - (ii) A partial structure of a Bayesian network is learned from the data on each group.
  - (iii) Sensitivity analysis is performed for each group, and the extent to which each candidate variable affects the objective variable is checked.
  - (iv) Steps (i)–(iii) are repeated after resetting the groups, if necessary.
  - (v) Based on the results of the sensitivity analysis of all groups, the explanatory variables suitable for each objective variable are confined.

Step 5. The whole structure of the Bayesian network is learned from the data while using the selected constraints.

6.4 Case Study of Healthcare Home Electronics: Blood-Pressure Monitor and Activity Monitor

6.4.1 Consumer Survey Data Used

The survey regarding home electronics for healthcare was performed using the Internet from April 1 to April 5 in 2014 using MyVoice Communications, Inc. The respondents to the survey were average Japanese consumers who were randomly chosen from the panels of this research firm. The number of valid responses was 11,334.

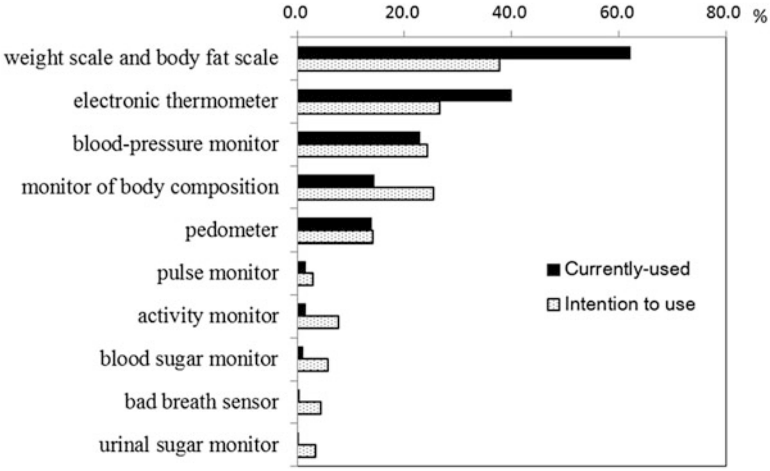

Fig. 6.1 Use of electronic healthcare products

6.4.2 Fundamental Statistical Results

Both the current use rate of healthcare electronics and the rate of the intention to use them in the future are indicated in Fig. 6.1.

To learn about the consumers' behavior, a blood-pressure monitor and an activity monitor were selected as samples. Both products increased their future intention of use. In the case of blood-pressure monitors, the current user rate was 22.9%, and the percentage of respondents who wanted to use them in the future was 24.3%. In contrast, the percentage of respondents who would like to use activity monitors that track and record the calories consumed for physical activities, such as walking, performing household chores, and doing desk work, greatly exceeded the current user ratio. The user rate increased from 1.5% to 7.7%, which was a very remarkable increase.

6.4.3 Learned Bayesian Network Structure

6.4.3.1 Features or Attributes

We extracted 40 attributes from the survey questionnaires. These attributes were divided into the following four major categories that were deemed to be related to the customer values on healthcare home electronics. The categories and the attributes within each category were as follows:

- Demographic attributes (DE: four attributes): These were answers to questions related to gender, age group, marital status, and household income levels.

- Health consciousness (HC: one attribute): The answers were divided into two categories, one consisted of those who had "high" health consciousness, and the other consisted of those who had "low" health consciousness.
- Healthcare home electronics (HHE: 15 attributes): Fifteen healthcare home electronics were taken up, and we determined the intention behind using each product. Several products are shown in Fig. 6.1.
- Product features that a respondent considers important when purchasing healthcare home electronics (PF: 20 attributes): These were "yes or no" answers to questions on 20 product features such as "Brand or Maker's Name," "Country of Production," "Design and Color," "Material Used," "Size," "Levity," "Price," "Multifunction," "High Performance," "Ease of Operation," "Energy Savings," "Easy Care," "High Durability," "Advanced Cooperation with Smartphone," "Long-Lasting Battery," "High Security," "Advertisement and TV Commercials," "Selling Well," "Salesperson's Advice," and "Word-of-Mouth Communication."

Three objective variables were selected: "Intention to use a blood-pressure monitor," "Intention to use an activity monitor," and "High HC."

6.4.3.2 Feature Selection

We performed sensitivity analyses against each objective variable. The variables that influence the "Intention to use a blood-pressure monitor," "Intention to use an activity monitor," and "High HC" are listed in Tables 6.1, 6.2, and 6.3, respectively. The average value of "Intention to use a blood-pressure monitor" had been 29.9% before we conducted the probabilistic inference. From Table 6.1, we can see that when there is interest in "Country of Production," the usage intention would increase from 29.9% to 40.6%. Then, the variable with the second highest influence is the age. People prefer to use a blood-pressure monitor more with increasing age.

Table 6.1 Variables influencing "Intention to use a blood-pressure monitor"

Ranking	Feature	Value	Intention of blood-pressure monitor (%)
1	Country of production	Yes	40.6
2	Age	50s or more	40.1
3	Easy-care	Yes	39.9
4	Long-lasting battery	Yes	39.8
5	Salesperson's advice	Yes	39.3
6	Advertisement and TV commercials	Yes	38.5
7	Word-of mouth communication	Yes	37.7
8	High performance	Yes	37.2
9	price	Yes	34.1

Table 6.2 Variables influencing "Intention to use an activity monitor"

Ranking	Feature	Value	Intention of activity monitor (%)
1	Advanced cooperation with smartphone	Yes	29.2
2	Long-lasting battery	Yes	22.1
3	Levity	Yes	17.3
4	Design and color	Yes	16.3
5	Multifunction	Yes	15.8
6	Easy operation	Yes	13.2
7	High performance	Yes	12.8

Table 6.3 Variables influencing "High HC"

Ranking	Feature	Value	Health consciousness high (%)
1	Age	50s or more	70.9
2	Sex	Female	66.9
3	Household income	High	64.3
4	Marital status	Married	62.1

Similarly, the average value of "Intention to use an activity monitor" had been 9.4% before we conducted the probabilistic inference. From Table 6.2, we can see that when there is interest in "Advanced Cooperation with Smartphone," the usage intention would increase from 9.4% to 29.2%. The variables with second and third highest influence are "Long-lasting battery" and "Levity." The activity monitor features should be able to work in conjunction with a smartphone; it needs to have a light body and long-lasting battery. These variables are different from those required for a blood-pressure monitor. Of course, some variables are required for both monitors, such as "Long-lasting battery."

The average value of "HC" had been 60.3% before the probabilistic inference was conducted. Table 6.3 shows that when a person is 50 years or more, the value of "HC" would increase from 60.3% to 70.9%.

Variables listed in Tables 6.1, 6.2, and 6.3 were selected to learn the whole structure of the Bayesian network. The greedy search algorithm was used while applying AIC as the information criterion.

6.4.3.3 Graph Structures of Bayesian Network

Figure 6.2 shows the whole Bayesian network structure that was learned by using the greedy search algorithm with AIC as a target index. Before starting to learn the structure, the three objective variables were set together, and the features selected by the sensitivity analyses were clearly designated as candidate explanatory variables. The resultant values of AIC and MDL were 168,272 and 86,153, respectively.

Figure 6.3 shows the whole Bayesian network structure that was learned by using the greedy search algorithm with AIC as the target index; the three objective

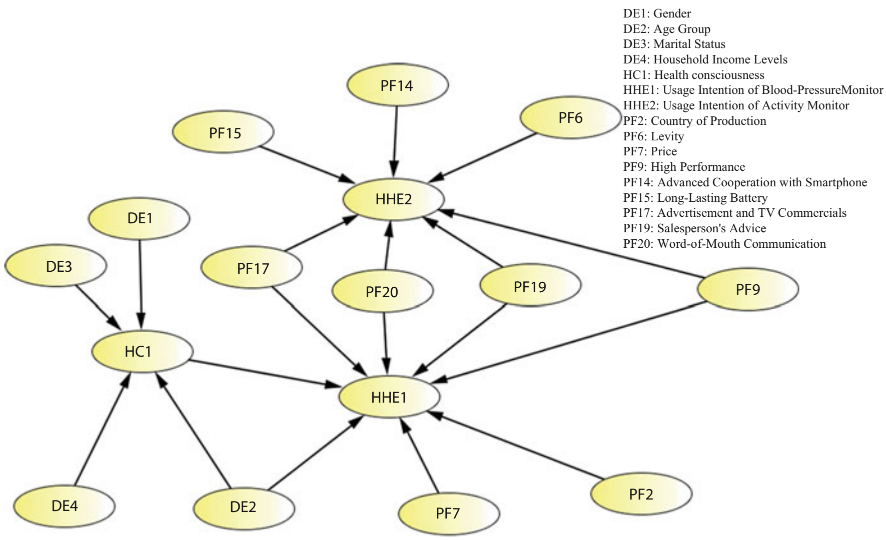

Fig. 6.2 A Bayesian network structure learned from data using the proposed method

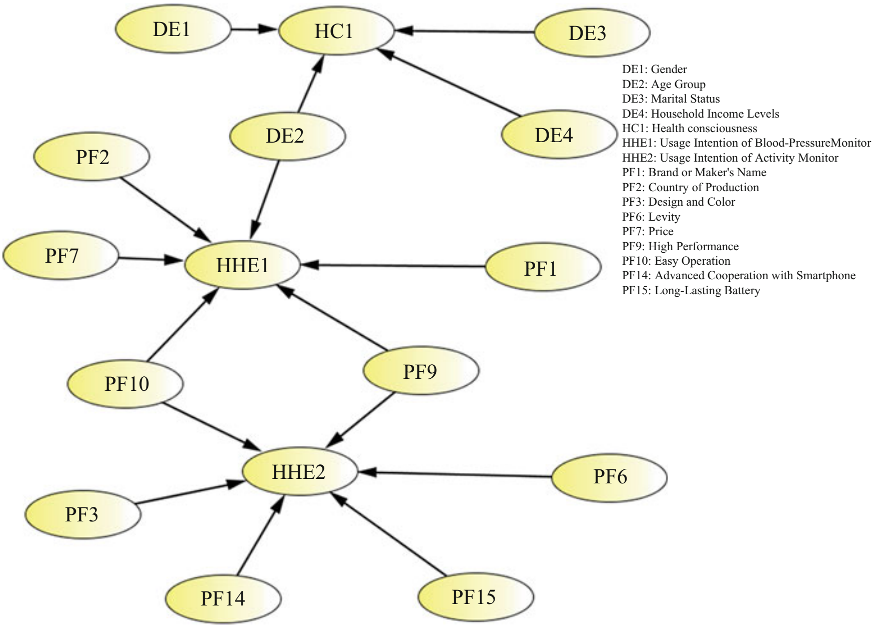

Fig. 6.3 A Bayesian network structure learned from data without using the proposed method

variables were set altogether, and all other variables equally had the possibility of being selected as explanatory variables. The resultant values of AIC and MDL were 194,944 and 98,198, respectively.

AIC provides an estimate of the relative quality of statistical models for a given data set. Given a collection of models for the data, AIC estimates the quality of each model relative to each of the other models. Thus, AIC provides a means for model selection. Also, the MDL principle picks the model with the smallest description length and balances the fit with complexity. The structure in Fig. 6.2 is better than that in Fig. 6.3 because the structure improves as the values of AIC and MDL reduce.

There are two major differences between the Figs. 6.2 and 6.3. First, "Advertisement and TV Commercials" and "Word-of-Mouth Communication" did not appear in Fig. 6.3. These variables have significant impacts on the usage intention of a blood-pressure monitor, as shown in Table 6.1. Second, the graph topologies were different, and especially, variables such as "HC" and "Age," directly affected the usage intention of a blood-pressure monitor in Fig. 6.2.

By using the proposed method, useful knowledge for the marketing of healthcare home electronics was found. Consumers would maximally want to use blood-pressure monitors, when the following product features were observed: high performance, reasonable price, and reputable country of production. Consumers would maximally want to use activity monitors, when the following product features were observed: high performance, a light body, a long-lasting battery, and the ability to work well with a smartphone. However, communication measures, such as advertisement of mass media, salesperson's advice, and personal word-of-mouth communication, were also important to boost the usage intension for both products. Increasing age and rising HC were more strongly related to the usage intention of blood-pressure monitors.

The proposed method for obtaining an appropriate structure for a Bayesian network by using sensitivity analyses in a stepwise fashion showed quite good performance. The sensitivity analyses are combinatorial trial experiments with probabilistic inference; therefore, the proposed method is appropriate for analyzing categorical data.

6.5 Conclusions

This study proposed a method for extracting useful knowledge from data by performing Bayesian network modeling in which the feature selections are executed using the sensitivity analysis for an objective variable in a stepwise manner. The Bayesian network technique has recently become popular for modeling an agent's behavior in ABSS, especially when a large amount of data is used. However, the problem was to determine how to learn the accurate structure of a Bayesian network from data when there were many variables and the search space became too wide. Our proposed method dealt with this problem.

This research demonstrated that the feature selection problem under multiple objective variables would be solved by decomposing the problem into an individual objective variable. The crucial points of the proposed method are as follows. Several hypotheses are generated for each objective variable, and Bayesian network structures are learned from data. Using each generated structure, sensitivity analysis is performed to determine the influential variables. Finally, a whole Bayesian network structure is learned from data by using the selected variables through the trial-and-error process. The proposed method provides a compact Bayesian network structure based on feature selections. Therefore, a domain expert can easily understand the relationships between the features and obtain useful knowledge leading to concrete strategic action.

The effectiveness of the proposed method was verified by a case study using questionnaire data about healthcare devices in the field of home electronics. The purpose of the proposed method was not only to accurately classify the objective variables but also to extract useful information regarding the consumers' attitudes and behaviors. From this perspective, the proposed method showed good performance.

The proposed method is straightforward; therefore, we can conclude that this method is applicable for other domain problems as well. One limitation of this method is that it needs a considerable amount of data. This is because the accuracy of the Bayesian network inference depends on the quality and quantity of data, although the level of the so-called "Big Data" is not necessary.

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Chapter 7
Analyzing the Influence of Headline News on Credit Markets in Japan

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Abstract This paper analyzes the influence of text information on credit markets in Japan, focusing on headline news, a source of information that has immediate influence on the money market and also which is regarded as an important source of information when making investment decisions. In this research, we employ an automatic text classification algorithm in order to classify the headline news into several categories. As a result of intensive analysis, we made the following findings (Antweiler W, Frank MZ J Financ 59:1259–1294, 2004): it is possible to build a headline news algorithm to an accuracy of 80% (Ben-Saud T Adopting a liability-led strategy. Pension management, April, pp 34–35, 2005); headline news has an influence on corporate bond spreads in Japan after items of news become public (Black F, Cox J J Financ, 31:351–367, 1976). The reaction of CDS spread is different from that of corporate bond spread even though both spreads relate to credit risk. These results are suggestive from both academic and practical viewpoints.

Keywords Fixed income · Credit risk · Asset management · Natural language processing · Information technology · Artificial intelligence

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7.1 Introduction

In asset management business, evaluating financial assets such as bonds and stocks is a major concern. The bond market is one of the major asset classes as well as stock, and the total amount of bond market in Japan is enormous, exceeding 560 trillion yen. Considering recent concerns about pension problems in Japan, it is now being recognized that taking liability into account is essential for pension fund management. Therefore, the issue of investment in fixed income securities assumed greater significance[1].

Japanese government bonds (hereinafter JGB) have been a major asset in the bond market in Japan. The total amounts of corporate bonds which include credit risk have also increased over the prior period and now exceed 80 trillion yen. Due to the recent economic downturn, the importance of accurate evaluation of corporate bonds has risen, and analyses regarding credit risk have drawn attention. CDS (credit default swap) market is also one of the most important credit markets, and the total CDS market in Japan exceeds 56 trillion yen. In order to invest in credit securities, such as corporate bonds, and CDS, it is essential to assess those securities swiftly and correctly use a numerous number of information such as financial statements and so on[2].

As for the assessment of credit risk, a great deal of research has been carried out, and many prominent models and analyses have been reported (Merton 1974; Black and Cox 1976; Longstaff and Schwartz 1995; Crosbie et al. 2000). Due to such outstanding analyses, the research of credit risk has developed noticeably. However, most prior studies deal with only numerical information, such as interest rates, stock prices, etc., and researches using information other than numerical data are lacking because of the difficulty of dealing with other types of information.

In practical asset management business, institutional investors make their investment decisions by utilizing various kinds of information, including textual information such as newspaper, in addition to numerical data. Also, there are several analyses suggesting that textual information conveys different information to financial markets when compared to numerical information (Wuthrich et al. 1998; Tumarkin and Tobert 2001; Takahashi et al. 2006, Tetlock (2007)). For example, Takahashi, Takahashi et al. (2009) focus on headline news which is commonly used as important textual information source for fund managers who belong to institutional investors and find that headline news has an influence on the stock market in Japan. Antweiler and Frank (2004) analyze bulletin boards and find a significant relationship between the number of contributions on bulletin boards and volatility of stocks on the US stock market.

Although analyses of textual data exhibit suggestive results for understanding the determinants of variations in asset prices, most preceding studies are undertaken

[1] For example, liability-driven investments (LDI) have drawn attention in the practical pension fund business (Ben-Saud 2005).

[2] Default risk is the key factor in their values and variations.

focusing on only the stock market. However, the importance of bond markets has been increasing, especially in Japan. Therefore it is necessary to uncover the mechanisms of asset price fluctuations in the bond market. In this article, we attempt to analyze the influence of textual information on credit markets in Japan. This research is significant from both practical and academic viewpoints.

With this in mind, this research focuses on headline news as a source of information for investors and analyzes the influence of headline news on credit markets. The remainder of the paper is organized as follows: First, we detail data and text mining techniques employed in this analysis. Next, we show results. Finally, we summarize this paper.

7.2 Data

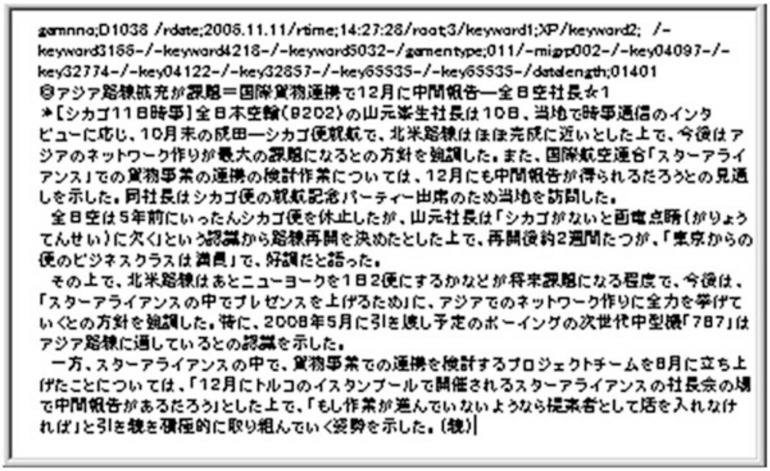
7.2.1 Headline News

This paper analyzes the reaction of credit markets to headline news transmitted through, for example, the computer-based news services of Bloomberg or Reuters. Headline news is one of the most important information sources for a fund manager (hereafter we will refer to "headline news" as NII (news of interest to investors)). We use the news data offered from JIJI Press which is one of the biggest news agencies in Japan. Naturally, the content of NII includes many different fields, such as business trends, macroeconomic indicators, the foreign market trends, information of individual stocks, etc. We found the following to be indicated:

- Domestic news reported through the mass media, international news such as Reuters, weather news, or news watched on television
- Statements released by the Bank of Japan or government agencies
- Market information, such as interest rates or exchange rates
- Analysts' comments or rating information from brokerage firms of rating companies
- A message or statement from CEOs or commentary on such statements by third parties

In credit markets such as the corporate bonds market and the CDS market, financial products which involve credit risk are traded. A corporate bond market is a traditional market where a company issues fixed-income securities for financing, while the CDS market is based on derivatives and can transfer only credit risk from party to another. CDS has rapidly increased in its size in recent years. In general, credit risk is measured by credit spread (difference in yield between JGB and corporate bonds). In this article, we analyze the relationship between such credit markets and NII.

In this analysis, we first extract specific news items in Japanese that seem likely to affect credit markets, such as "company scandal," "mergers and acquisitions,"



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◎アジア路線拡充が課題＝国際貨物連携で12月に中間報告―全日空社長☆1
＊［シカゴ11日時事］全日本空輸〈9202〉の山元峯生社長は10日、当地で時事通信のインタビューに応じ、10月末の成田―シカゴ便就航で、北米路線はほぼ完成に近いとした上で、今後はアジアのネットワーク作りが最大の課題になるとの方針を強調した。また、国際航空連合「スターアライアンス」での貨物事業の連携の検討作業については、12月にも中間報告が得られるだろうとの見通しを示した。同社長はシカゴ便の就航記念パーティー出席のため当地を訪問した。
全日空は5年前にいったんシカゴ便を休止したが、山元社長は「シカゴがないと画竜点睛（がりょうてんせい）に欠く」という認識から路線再開を決めたとした上で、再開後約2週間たつが、「東京からの便のビジネスクラスは満員」で、好調だと語った。
その上で、北米路線はあとニューヨークを1日2便にするかなどが将来課題になる程度で、今後は、「スターアライアンスの中でプレゼンスを上げるため」に、アジアでのネットワーク作りに全力を挙げていくとの方針を強調した。特に、2008年5月に引き渡し予定のボーイングの次世代中型機「787」はアジア路線に適しているとの認識を示した。
一方、スターアライアンスの中で、貨物事業での連携を検討するプロジェクトチームを8月に立ち上げたことについては、「12月にトルコのイスタンブールで開催されるスターアライアンスの社長会の場で中間報告があるだろう」とした上で、「もし作業が進んでいないようなら提案者として活を入れなければ」と引き続き積極的に取り組んでいく姿勢を示した。（続）

Fig. 7.1 Example of headline news (in Japanese)

"evaluation of an analyst," or "statements of CEOs." Then, we analyze how the stock price of the company that was reported in the news changes before and after. Figure 7.1 is a sample of NII, in Japanese, we used for analysis.

Each news article includes the following materials (Antweiler and Frank 2004): news code of JIJI Press (Ben-Saud 2005), delivered date (Black and Cox 1976), delivered time (Crosbie et al. 2000), system code (Lewis 1998), length of this news (Longstaff and Schwartz 1995), and body of news (Fig. 7.1). When NII is for a specific company, the identification code of the target company is described in the body of news, like the form of <9202>. We use this cord to identify which company the news describes.

We collect the news updated between 2006/8/10 and 2006/11/24. And we define this period as a period of analysis. The total number of news articles published through the period by JIJI Press is 346,975—an enormous number. We choose companies that have been listed on the first section of the Tokyo stock exchange market (TSE1) and have issued corporate bonds during the analysis period. The number of companies for analysis is 185. Table 7.1 shows the basic statistics of news that we analyzed. As shown in Table 7.1, the total number of news articles about the company for analysis is 6172 and accounts for about 2% of all news. The average number of NII published on one day for analysis is 83.

As for the CDS market, the number of companies for analysis is 152, and the number of articles regarding those companies is 4597. Compared to the corporate bond market, CDS market is a growing market; therefore, the number of company that has news during the analysis period is less than the corporate bond market.

This research analyzes the influence of headline news on corporate bonds and CDS spreads by analyzing data before, during, and after NII are published.

Table 7.1 Basic statistics about news

	ALL news	News about a company	News about a company (TSEl)	News about a company (TSEl & bond)
Total number of articles	345,975	30,052	13,402	6172
Average number of articles (per one day)	3336	320	144	83
Maximum number of articles (per one day)	8588	741	460	243
Minimum number of articles (per one day)	172	0	0	6

7.2.2 Spread Data

7.2.2.1 Credit Spreads on Corporate Bonds

A credit spread of corporate bonds is calculated by subtracting a compound yield of Japanese government bonds with the same maturity of the target corporate bond from a compound yield of that corporate bond[3]. In estimation, BPI prices which are employed for calculation of index (NOMURA-BPI which is one of the most commonly used bond indices in Japan) are used. We analyze corporate bonds of between 3 and 5 years' maturity[4], and when a company issues several bonds during corresponding maturity, we analyze bonds with the longest maturity. We put these conditions for the following reasons (Antweiler and Frank 2004): corporate bonds with maturity from 3 years to 5 years have the largest in number (Ben-Saud 2005), and it is necessary to analyze bonds with similar maturity in order to get rid of the influence of maturity in analyses, because changes in spreads are different according to maturity. With the abovementioned rule, we identify one corporate bond, although a company issues several bonds.

We measure the changes in spreads based on the date when NII is released. As Fig. 7.1 shows, all news articles include a time stamp, and we can therefore make use of it. When the news is released in the morning of a weekday, the bond is open to invest on the same day. On the other hand, when the news is released later in the day or on the weekend of holiday, the bond is not open to investment until the next trading day.

[3]In this analysis, first, we estimate JGB yield curve and then apply it to establish estimation of spreads.

[4]We put these conditions for the following reasons (Antweiler and Frank 2004): corporate bonds with maturity from 3 years to 5 years have the largest in number (Ben-Saud 2005), and it is necessary to analyze bonds with similar maturity in order to get rid of the influence of maturity in analyses, because changes in spreads are different according to maturity.

We measure the changes in spread with daily data from 30 days before to 30 days after the release of the relevant NII. In order to remove the influence of changes on the credit market as a whole, we calculate the excess spread by removing the average spread of all corporate bonds from the corporate spread of the target company (hereinafter referred to as "excess spread").

7.2.2.2 CDS Spread

As for CDS spread, we employ the credit swap default index produced by Itraxx Japan. The credit swap default index is a representative index indicating the movement of the credit derivative market in Japan[5]. We analyze CDS spreads with a maturity of 5 years—the most commonly traded on the CDS market. We measure the changes in spread in the same way described in the previous section and analyze the excess spreads (hereinafter CDS), which are calculated by removing average spreads of all CDSs from a CDS spread of the target company.

7.3 Analysis Method

In this paper, we analyze whether the information disseminated by news has an impact or not on the credit spread of a target company. The impact of this information naturally depends on its content. We split NII into three basic categories: positive negative, and neutral.

7.3.1 Naïve Bayesian Classifier Algorithm

We use the naïve Bayesian classifier method to interpret news, which is frequently used for text mining (Lewis 1998). It is a well-known and well-established algorithm such as the decision tree, K-nearest neighbors, or the neural network. The classification methodology of the naïve Bayes' system is easy to understand. Compared to other methods, naïve Bayes offers particular ease of interpretation (Mitchell 1997). Using the naïve Bayes method, an algorithm can be constructed from learning data with a limited number of labeled documents that will nevertheless be effective for large quantities of data (Nigam et al. 2000).

Let n be the number of keywords that characterize a text data. By using these keywords, a text data is described by the n-tuples vector $x_1, x_2, \ldots, x_n$ (Salton and McGill 1983). x_i takes the value of 0 or 1; it means whether the i-th keyword exists in the text data or not. The method of using IDF or an information entropy besides

[5] Itraxx Japan produced the spread data; we use it for analyses as it is.

digital data has also been proposed (Sparck 1972; Salton and Yang 1973). Let's assume that the class that the text belongs to is c. For finding the class c, we try to assign the most probable target value of the following equation:

$$c = \arg\max_{c} \left(P\left(c \mid x\right)\right) = \arg\max_{c} \left(\frac{P\left(x \mid c\right) P(c)}{P(x)}\right) = \arg\max_{c} \left(P\left(x \mid c\right) P(c)\right). \tag{7.1}$$

To expand Eq. (7.1), we apply the Bayes theorem and the fact that $P(\mathbf{x})$ takes the same value in all classes. Furthermore, we assume that occurrences of each key word are independent of each other under the condition that class c has been given. So, $P(\mathbf{x}| c)$ in Eq. (7.1) is expanded as follows:

$$P\left(\mathbf{x}|c\right) = P\left(x_1, x_2, \cdots, x_n|c\right) \approx \prod_{i=1}^{n} P\left(x_i|c\right) \tag{7.2}$$

By using Eq. (7.1) and Eq. (7.2), the class $\widehat{c}$ that the text belongs to is as follows:

$$\widehat{c} = \arg\max_{c} \left(P\left(c|\mathbf{x}\right)\right) = \arg\max_{c} \left(P(c) \prod_{i=1}^{n} P\left(x_i|c\right)\right) \tag{7.3}$$

So, $\widehat{c}$ is determined by calculating both probability that each class will occur and probability that each keyword will exist in each class. By using labelled training data, $P(c)$ can be defined from the relative frequency of each class, and $P(x_i| c)$ can be defined from the relative frequency of keywords in each class. We then verify classification accuracy of the algorithm that we made using other test data.

In this paper, we employ three categories of news (NII): "good news," "bad news," and "neutral news." We chose each 400 news data at random as training data and test data.

7.3.2 Credit Spread Analysis

We calculate the mean value of excess spread changes for each type of news (good news, bad news, or neutral news), and we perform statistical tests to examine whether a significant difference between the excess spread changes among the news categories exists or not. We employ the Welch test to measure these differences. Also, we employ credit rating data and stock prices to make further analyses.

7.4 Results

We explain the results of analysis in this section. First, we show the result of the text classification by naïve Bayes, and then we show the results about the effects of news. Finally, results from the analysis employing credit ratings and stock returns are explained.

7.4.1 Results of the Naïve Bayes Classification Algorithm

We chose 400 news data at random to use as training data, which we categorized as good news, bad news, or neutral news, from the contents of the NII in order to give a teacher label. We show the classification results in Table 7.2. We find that good news accounts for about 49% of all types of News.

We perform morphological analysis and pattern matching to extract keywords from training data. Although the number of keywords first extracted from training data is 1360 pieces, we select 205 keywords by the probability that each keyword will exist in each class and the classification result of training data. We show in-sample classification result of training data in Table 7.3. Although it is the result of in-sample analysis, we can make an algorithm that has about 80% classification accuracy.

Next, we verified the accuracy of the naïve Bayes text classification algorithm using test data. We also give a teacher label of good news, bad news, and neutral news to test data. We show the classification results in Table 7.4. The percentage of good news is 46% and is the highest of the three categories of news.

We classify test data into three classes using naïve Bayes algorithm that we made from learning data. Table 7.5 shows the classification results. The algorithm which we made has about 78% of classification accuracy when applied to out-of-sample data.

Table 7.2 News classifications of training data

Type of news	Good	Bad	Neutral
Number of news	197	97	106
Ratio	49.25%	24.25%	26.50%

Table 7.3 In-sample classification result by training data

	Label by the result of Naïve Bayes	Teacher label: Good	Bad	Neutral
The number	Good	179	24	24
	Bad	2	66	9
	Neutral	16	7	73
The Probability	Good	90.9%	24.7%	22.6%
	Bad	1.0%	68.0%	8.5%
	Neutral	8.1%	7.2%	68.9%

Table 7.4 News classifications of test data

Type of news	Good	Bad	Neutral
Number of news	185	90	125
Ratio	46.25%	25.50%	31.25%

Table 7.5 Out-of-sample classification result by training data

		Teacher label		
	Label by the result of Naïve Bayes	Good	Bad	Neutral
The number	Good	168	27	35
	Bad	3	58	5
	Neutral	14	5	85
The probability	Good	90.8%	30.0%	28.0%
	Bad	1.6%	64.4%	4.0%
	Neutral	7.6%	5.6%	68.0%

Table 7.6 News classifications of whole data

Type of news	Good	Bad	Neutral
Number of news	10098	2418	4463
Ratio	59.47%	14.24%	26.29%

We classify whole data (13,402 news) using this algorithm. We show the classification result in Table 7.6.

Table 7.6 shows that good news accounts for about 59% of all type of news, and the percentage of good news in the total data is slightly higher than the percentage of good news in the learning data or test data. Table 7.5 shows that although the algorithm that we made has about 80% classification precision for whole data, it occasionally clarifies bad news as good news. Therefore, it is reasonable to assume that good news is slightly overrepresented in the results for the total data. To make an algorithm with higher classification accuracy is an important future project.

In the following section, we analyze the differences in mean excess return of each class.

7.4.2 Analysis of the Influence of NII on the Corporate Bonds Market

We measure excess spread changes before and after the announcement of each type of NII. Then we calculated the mean value of excess spread changes of each type of NII. We performed the Welch test to examine whether a significant difference between the average excess spread changes among the news of each type exists or not. We find that the level of an excess spread change is the order of good news, neutral news, and bad news, and there are significant differences in excess spread change of each type of news. From here, we explain the results of the Welch test between good news and bad news, since the difference of return of these classes is most important to make investment decisions. Table 7.7 shows the results of the Welch test between excess return of good news and that of bad news.

Table 7.7 Results of Welch test (corporate bond)

		Day					
		−30	−20	−10	+10	+20	+30
Average spread	Good news	−0.057%	−0.056%	−0.051%	−0.071%	−0.117%	−0.159%
	Bad news	0.158%	0.154%	0.156%	0.056%	0.201%	0.280%
	Diff.	−0.214%	−0.210%	−0.206%	−0.127%	−0.317%	−0.440%
Welch test	*t* value	−19.91	−14.39	−7.55	−5.06	−7.32	−10.88

As shown in Table 7.7, the excess spread change of good news is tightening more than that of bad news after announcement. This result shows that it could be possible for fund managers to obtain an excess return by incorporating news into their investment strategy. And Table 7.7 shows that the naïve Bayes method is valid for this analysis. Furthermore, Table 7.7 also shows that the effect before News is the same as the effect after news. So it is confirmed that the effect of news has already been incorporated before news was published in the market. As we show in Sect. 7.2, the mean number of published news articles per day is 83. Therefore it could be that the news with the same contents is sometimes reported continuously and the influence of this news overlaps. Takahashi et al. 2004 also found the same effect.

Figure 7.2 exhibits the transition of cumulative excess spread changes. Figure 7.2 shows that cumulative excess spread changes 30 days after the release of good news, neutral news, and bad news; the order is the same as shown in Table 7.7. From previous studies (e.g., Takahashi et al. 2009) of stock market behavior to NII, one would expect the market to anticipate coming news and begin to adjust. It is reasonable to assume that traders have access to relevant information reflecting the performance of corporate bonds. However, in the bond market (in contrast to the stock market), traders react only after the public announcement of NII, and even in this case a relatively gradual trend is established rather than an immediate readjustment. These results indicate that there is the potential for earning excess return in the bond market. The behavior of neutral news is similar to that of bad news, and this may indicate that news categorized as neutral by the algorithm could in fact contain information suggesting credit risk. These results show that there is room for improvement in the text mining method. Improving our methodology is a future goal.

7.4.3 Analysis of the Influence of NII on CDS Market

This section analyzes the influence of the news on the CDS market using the same analyses we have used thus far. Table 7.8 shows the result of the Welch test between excess return of good news and that of bad news. Figure 7.3 shows the transitions of

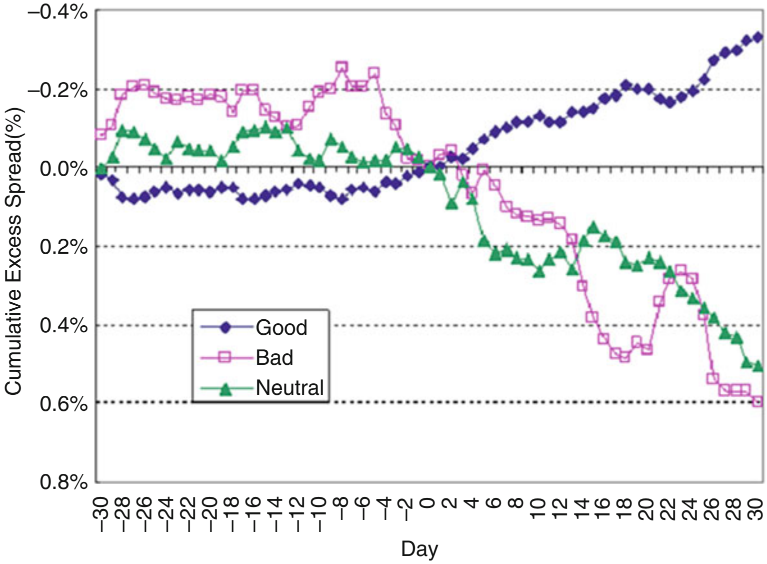

Fig. 7.2 Transitions of cumulative excess spread (corporate bond)

Table 7.8 Results of Welch test (CDS)

	Day						
		−30	−20	−10	+10	+20	+30
Average spread	Good news	−0.179%	−0.150%	−0.094%	−0.005%	0.002%	−0.013%
	Bad news	0.812%	0.678%	0.413%	−0.038%	−0.094%	−0.155%
	Diff.	−0.991%	−0.828%	−0.507%	0.033%	0.096%	0.142%
Welch Test	*t* value	−15.29	−10.77	−6.33	3.69	5.06	6.22

cumulative excess spread. Significant differences in excess spreads between good news and bad news could not be confirmed in this case[6]. The information that NII includes is already incorporated in the CDS market. Although both spreads—corporate bond spread and CDS spread—reflect credit risk, the reaction to that of NII is different. This result indicates that there are factors other than credit risk which contribute to spread changes. This research indicates that it is necessary to analyze the market more elaborately in order to uncover the determinants of variation in asset prices.

[6]Similar tendencies are observed in analyses of the stock market. The reaction of the CDS market is similar to that of the stock market.

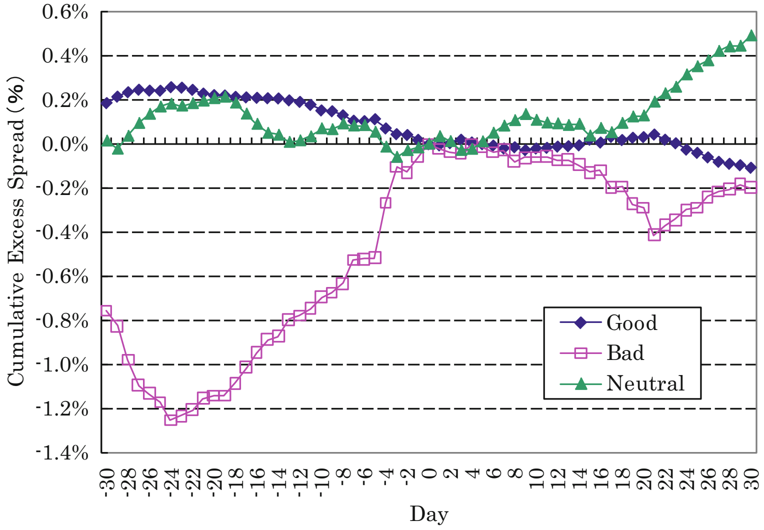

Fig. 7.3 Transitions of cumulative excess spread (CDS)

Table 7.9 List of the number of news at each credit rating

	(1) NII articles	(2) No. of companies	(1)÷(2)
AA or Higher-grade	1126	50	23
A	2626	76	35
BBB or Lower grade	1960	39	50
No rating	460	20	23
Total	6172	185	33

7.4.4 Analysis of Spread with Credit Rating

In this section, we classify the data into three categories based on credit rating—AA or higher-grade, A, and BBB or lower-grade. Table 7.9 shows the number of news in each category. As can be seen, the corporate bonds rated as A have the largest number among the categories. As for the average number of NII per company, the lower the credit rating, the higher the increase.

Table 7.10 shows the results of the Welch test at each credit rating category. As for corporate bonds rated as A and BBB or lower-grade, on the whole excess spreads of good news are less than bad news which is consistent with previous results. On the other hand, different results are confirmed in the case of AA or higher-grade. Companies rated as AA or higher-grade don't seem to have so much anxiety regarding default risk, and this may explain the difference in the results[7].

[7]Further research on companies with high credit rating is planned for the future.

Table 7.10 Result of Welch test (corporate bonds)

Credit rating		Day						
			−30	−20	−10	+10	+20	+30
AA or Higher	Average spread	Good news	0.018%	0.002%	0.006%	−0.012%	−0.001%	0.018%
		Bad news	−0.017%	−0.020%	−0.009%	0.025%	−0.021%	−0.043%
		Diff.	0.035%	0.035%	0.015%	−0.036%	0.020%	0.061%
	Welch Test	t value	5.22	4.73	1.51	−5.31	1.49	5.06
A	Average spread	Good news	−0.151%	−0.124%	−0.094%	−0.078%	−0.127%	−0.161%
		Bad news	0.337%	0.269%	0.236%	0.166%	0.246%	0.328%
		Diff.	−0.487%	−0.392%	−0.330%	−0.244%	−0.373%	−0.490%
	Welch test	t value	−19.27	−16.33	−8.80	−5.50	−11.76	−15.38
BBB or Lower	Average spread	Good news	0.226%	0.124%	0.017%	0.010%	0.040%	−0.041%
		Bad news	1.371%	1.233%	0.991%	0.408%	1.006%	1.885%
		Diff.	−1.145%	−1.109%	−0.974%	−0.398%	−0.966%	−1.927%
	Welch test	*t* value	−11.40	−9.10	−5.10	−4.92	−5.02	−6.66

Table 7.11 shows the results of the same analyses on CDS spreads. When we compare the excess spreads before and after the announcement of each type of NII, the spreads before the release of NII tend to be larger than after release. This tendency can also be seen in the previous results shown in Table 7.8. The disparity between bad news and good news seen prior to the release of NII in Fig. 7.3 (where the market appears to reach far more dramatically in anticipation of bad news than good) can also be observed in each credit rating category.

7.4.5 Analysis of the Relationship Between the Bond Market, the CDS Market, and the Stock Market

This section investigates the differences in reaction to the announcement between corporate bond spreads, CDS spreads, and stock return using the 6127 NII described in Table 7.1. We calculate the mean value of each type of news one by one and then

Table 7.11 Result of Welch test (CDS at each credit rating)

Credit rating		Day						
			−30	−20	−10	+10	+20	+30
AA or Higher	Average spread	Good news	−0.077%	−0.064%	−0.023%	0.052%	0.087%	0.074%
		Bad news	0.317%	0.309%	0.194%	−0.120%	−0.254%	−0.302%
		Diff.	−0.394%	−0.372%	−0.217%	0.172%	0.341%	0.377%
	Welch Test	*t* value	−17.35	−11.27	−6.39	5.56	9.51	13.83
A	Average spread	Good news	−0.180%	−0.139%	−0.052%	0.024%	−0.065%	−0.174%
		Bad news	0.259%	0.187%	0.119%	0.110%	0.289%	0.467%
		Diff.	−0.439%	−0.326%	−0.171%	−0.086%	−0.354%	−0.641%
	Welch test	*t* value	−13.10	−9.82	−5.26	−1.55	−6.51	−9.59
BBB or Lower	Average spread	Good news	−0.292%	−0.251%	−0.235%	0.001%	0.157%	0.284%
		Bad news	4.145%	3.394%	2.200%	0.295%	0.141%	0.08%
		Diff.	−4.437%	−3.645%	−2.435%	−0.295%	0.016%	0.204%
	Welch test	*t* value	−13.40	−9.29	−4.48	−4.09	0.18	2.72

calculate the mean value of excess spread changes for each type of NII[8]. Figure 7.4 shows the difference in cumulative excess return of each asset 30 days after announcements[9].

The results confirm that the behavior of CDS is similar to that of the stock market. Corporate spread has a different characteristic from both the stock market and CDS. The excess return of corporate bonds after NII announcement is larger than before the NII announcement. These results indicate there is a possibility for fund managers of fixed-income securities to achieve excess returns by utilizing NII. Figure 7.4 shows that stock reacts to the NII faster than corporate bonds. In the next section, we elaborate on the relationship between corporate bond return and stock return.

[8] As for stock, we calculate excess return by subtracting average return from stock return of the target company in order to remove the influence of market movement as a whole.

[9] As for corporate bond and CDS, an excess return is calculated as follows: duration × spread change. We set the duration of corporate bonds at 4 years and the duration of CDS at 5 years which reflects the actual mean duration of each market.

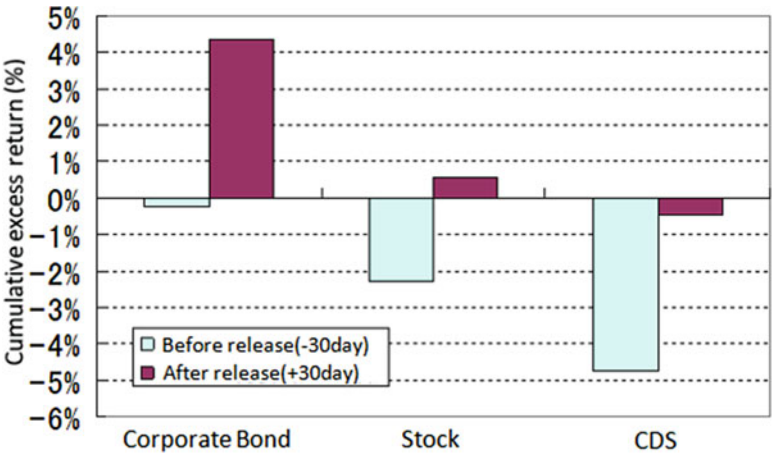

Fig. 7.4 Difference in cumulative excess return (Corporate bond, CDS, and Stock)

Table 7.12 Results of Welch test (corporate bond)

Regression coefficient	*t*-value
−0.0032	−22.2
R-square	0.07
Adjusted *R*-square	0.07
N	6172

7.4.6 The Relationship Between Corporate Bonds and Stock

In this section, we conduct regression analysis to evaluate the degree of stock return as a determinant of the variation in credit spread. In particular, we attempt to calculate whether the influence of NII remains in variations in credit spread of corporate bonds after removing the influence of excess stock returns. In other words, how accurate is the anticipatory movement in the stock market as a predicator of variations in credit spread in the corporate bonds market after the announcement of NII? And what excess information does the announcement of NII provide which in not anticipated in the stock market yet which has an influence on the reaction of the corporate bonds market? The linear regression equation—examining excess spread variations 30 days after NII announcement and excess return 30 days before NII announcement—is as follows (Table 7.12):

$$\text{ExcessSpread}_{\text{Corporate bond},+30\text{day}} = \beta \cdot \text{ExcessReturn}_{\text{Stock} \quad -30\text{day}} + \varepsilon. \tag{7.4}$$

In order to analyze the influence of NII on corporate spread changes, we analyze error terms of the equation through the same analysis we have conducted so far. Figure 7.5 shows the differences in cumulative excess spread of each credit rating. As for the results for credit rating A, AA, or higher, cumulative excess spreads

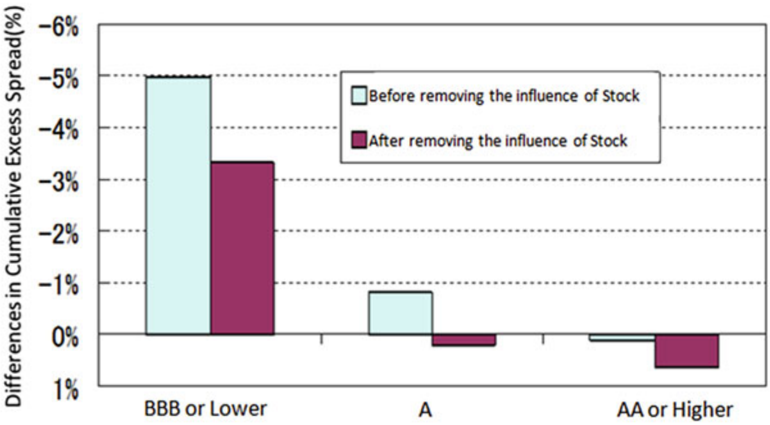

Fig. 7.5 Difference in cumulative excess corporate bond spread

become almost zero. These results suggest that the influence of NII on credit spread changes disappears after the influence of stock is removed. On the other hand, looking at the differences in cumulative excess spread of credit rating BBB or lower, it is confirmed that the influence of headline news remains. This result suggests that the corporate bond market in Japan might not fully incorporate information available into bond prices swiftly and correctly, and therefore it may be possible to achieve excess returns by investing in corporate bonds utilizing information from NII. If this interpretation is accepted, these results are suggestive from both academic and practical points of view.

7.5 Summary

This article analyzes the influence of NII (news of interest to investors)—one of the most frequently used sources of information in asset management—on the corporate bond market in Japan. In this analysis, we employ text mining techniques and make the following findings (Antweiler and Frank 2004): we are able to construct a text categorization system that has about 80% classification accuracy (Ben-Saud 2005); this system extracts effective information regarding credit spreads from NII (Black and Cox 1976); the reactions of assets, corporate bonds, CDS, and stock are different from each other. Significantly corporate bond spread reacts to NII after it is announced, whereas the stock market tends to move pre-announcement in anticipation. This suggests there is a possibility for fund managers to achieve excess return from credit markets and also exhibit the suggestive results. Overall, our analyses shed light on a key determinant of variation in credit spreads in Japan's credit markets—namely, the influence of NII. Our analyses have touched on the CDS market, but it is our opinion that there is scope for a study of greater depth and detail. We intend to address this in future papers. Also, while the text mining techniques we employed for our work in this paper proved to be effective and revealing, some fine-tuning of the technique will surely lead to improved accuracy and more penetrating analysis: this is also a goal for the future.

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Chapter 8
Consideration on an Integrated Approach to Solving Industrial Issues Through Surveys, Statistics, and Simulations

Yasuo Kadono

Abstract In order to aim for a deeper understanding of the complex and multifaceted issues in Japan's information service industry, we try to develop an integrated approach of data obtained from issue-oriented large-scale fact-finding surveys, statistical analyses based on dynamic modeling, and simulations. The integrated approach should be possible to develop evidence-based visualization of industry growth scenarios by integrating intellectual instruments that have hitherto evolved separately, such as social surveys, management theory, statistical analyses, and simulation models. Also, it can be developed to design plans for the management of technology as a national strategy, through visualization of a variety of scenarios, ranging from optimistic to pessimistic. And, it has potential to be expanded and generalized to illuminate any industrial sector in any country.

Keywords Integrated approach · Issue analysis · Social survey · Statistical analysis · Agent-based modeling · Simulation · Innovation · IT management · Software engineering

8.1 Introduction

Managing information technology (IT) is one of the most important and challenging aspects of contemporary business. As IT is a fundamental driver of competitiveness for companies in a wide variety of business sectors, it is essential that the strategies and practices of IT management are well understood. However, from the viewpoint of the demand side of IT, many companies in Japan that use enterprise IT systems have not been fully satisfied with the speed of delivery, quality, cost, or productivity

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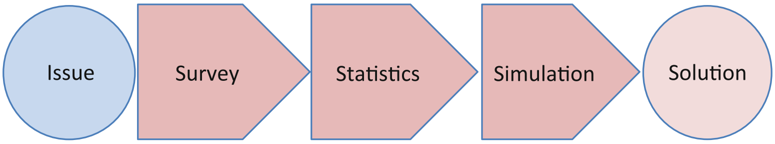

Fig. 8.1 Integrated approach

of software delivered by IT vendors, although the ultimate goal of Japanese IT vendors is to serve as catalysts for their customers' IT management. Conversely, from the supply-side viewpoint of IT, total sales of the Japanese information service industry have grown at a sluggish pace since reaching 10 trillion yen in 2005. It still, however, has a considerable presence in the world. In fact, in 2016 fiscal year, the information service industry was a 10,993,032 million yen market in Japan, of which 7,917,970 million yen was for software development and programming; orders for software totaled 6,748,509 million yen, accounting for 61.4% of the entire information service industry, while the software products market was 1,169,461 million yen (METI 2017).

In this paper, in order to meet the issues of the Japan's information service industry, we consider a new research scheme to integrate issue-oriented large-scale fact-finding surveys, results of statistical analyses, and future scenarios visualized for the Japanese software industry (Fig. 8.1) (Kadono 2011, 2015b). First, we conducted literature survey and interviews with experts in the IT industry. Second, we designed a large-scale survey of the enterprise software industry in Japan, administered it, and developed a tool to measure software engineering capabilities, in collaboration with the Ministry of Economy, Trade and Industry (METI). Third, using dynamic modeling, we empirically verified that human resource development in IT firms leads to improvement in their operational software engineering capabilities and that improvement in their software engineering capabilities tends to lead to long-term improvement in their business performance. Fourth, we tried to visualize future scenarios in the Japanese software industry through agent-based simulation.

8.2 Issues

IT vendors in Japan face a wide range of old and new issues in their business environment. These include the need to respond to rapid technological innovations, an orientation toward custom-made applications for the domestic market, global competition with new entrants from emerging countries, e.g., China, India, man-month-based multilayer subcontractors, leadership of senior managers at IT vendors, software engineers' skill building, and IT management in user companies.

Based on the interviews with over 50 experts in the field of IT in Japan and the United States, the above issues of IT management is thought to be mainly derived

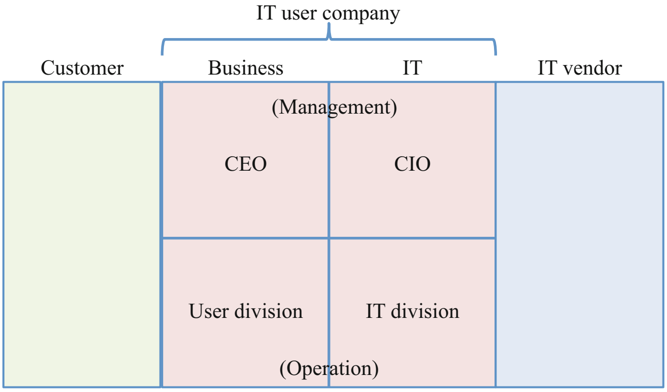

Fig. 8.2 Stakeholders in IT management

from the complicated relationships of stakeholders and historical background of the information service industry in Japan.

First, organizational structures in IT systems are complex. Its stakeholders include not only IT user companies as the demand side but also IT vendors as the supply side. Furthermore, the business environment surrounding IT user companies includes customers, competitors, collaborators, industrial structures, states, and society as a whole (Kadono 2015a).

Figure 8.2 indicates the stakeholders in IT management. The horizontal axis represents customers; IT user companies, including two decision-making domains, i.e., business and IT; and IT vendors. Besides these stakeholders, we can also imagine policymakers and academia in the horizontal axis. The vertical axis represents two decision-making levels: management and operation of IT user companies. From the viewpoint of user companies, the area enclosed by these two axes represents organizations or divisions that correspond to domains and levels of decision-making: chief executive officer (CEO), chief information officer (CIO), user divisions, and IT divisions.

The essential issue in IT management is to answer the question of senior managers, such as the CEO and CIO: How does the company create business value from the use of IT? However, many companies in Japan that use enterprise software have not been fully satisfied with the quality, cost, and productivity of software that IT vendors deliver, or with the speed of delivery.

In addition, IT user companies are not monolithic organizations. The user division of an IT user company tends to demand many changes in current IT systems, which do not necessarily bring about a favorable business impact for the company. On the other hand, the IT division of an IT user company tends to focus on discussing the use of new technology. Therefore, the CIO needs to take active responsibility for aligning the business impact and the IT usage of the company. However, in reality, CIO and IT division of an IT user company heavily rely on IT vendors for making decisions on IT issues in the company.

Second, in a historical context, it is instructive to consider the Japanese software industry structure from the perspective of path dependence (Arthur 1989), i.e., the origins of the companies. Japanese software vendors can be classified into three categories according to the type of company from which they originated: hardware manufacturers, users, and independent vendors.

Manufacturer spin-off vendors are defined as hardware suppliers; they include firms such as computer makers, e.g., Fujitsu, NEC, Hitachi, and IBM; or subsidiary companies under the control of hardware suppliers. In the early days of the Japanese information service industry, manufacturer spin-off vendors, as well as Nippon Telegraph and Telephone Public Corporation (Dendenkosha), i.e., the precursor of Nippon Telegraph and Telephone Corporation (NTT), established distinctive competencies (Selznick 1957) due to time compression dis-economies (Dierickx and Cool 1989) based on governmental policies and support.

User spin-off vendors are defined as subsidiary companies of buyers, i.e., IT user companies. Particularly in the 1960s and 1970s, leading computer users such as steel companies and financial institutions increasingly began to establish subsidiary software vendors because close relationships were desired for their business purposes. Some are thought to have gained inimitable capabilities, including expertise in specific functions and unique products/services. Therefore, the parent companies of user spin-off vendors might not be concerned about their business performance attributable to their management policy.

Independent vendors are defined as neither manufacturer spin-off vendors nor user spin-off vendors; they include firms such as system integrators, e.g., NTT DATA and Nomura Research Institute, and so many small- or medium-sized vendors.

In addition, because sustaining shop-floor usability is given priority over introducing technological innovation when IT is deployed in user companies in Japan, the dynamics of user–vendor interactions enable the development of finely tuned custom-made applications (Baba et al. 1995). This tends to establish long-lasting relationships between user companies and IT vendors, in particular, manufacturer spin-off and user spin-off vendors. Thus, the development of custom-made applications can cause a high entry barrier for newcomers from home and abroad, coupled with the perspective of path dependence, i.e., origins of vendors. As a result, the Japanese software industry has not established transparent relationships with the international market. This fact, coupled with the Japanese language barrier, has resulted in the Japanese software industry having for some time been described as a maze or as having “Galapagos syndrome.”

We address these issues relating to the Japanese software industry as part of the management of software engineering innovation.

8.3 Surveys

Although we look at the whole picture of information service industry in Fig. 8.2 and conducted five-time large-scale surveys on both the supply and demand sides

(Kadono 2015a), we focus on the supply side, i.e., IT vendor and information service industry, in this paper.

The first step for the Japanese software industry to achieve sustained success by solving issues relating to managing software engineering innovation is to grasp an appropriate perception of the present situation in the industry. Therefore, the research objectives in the research are:

- To assess the achievements of the software engineering capabilities, as represented by IT vendors in Japan
- To better understand the mechanisms of how software engineering capabilities relate to IT vendors' business performance and business environment

In other words, we need to understand how software engineering capability as a core competence (Prahalad and Hamel 1990) for the industry is significant for achieving medium- and long-term success.

To achieve these research objectives, we developed a measurement model called software engineering excellence (SEE). An aim of the research is to encourage innovation; therefore, in developing the SEE measurement model, state-of-the-art cases were surveyed by more than 50 experts in academic, business, and governmental circles in Japan and the United States, and literature reviews relating to software engineering disciplines were conducted in the broadest sense, focusing on the management of innovation. The scope of the survey includes Barney's resource-based view of vendors, informed by paying attention to factors such as degree of rarity and inimitability of management resources (Barney 2007), as well as software engineering disciplines (ISO/IEC/IEEE 2010; IEEE, Computer Society 2013; CMU 2014), and so on (Fujimoto 2003; Dodgson et al. 2008; Tidd and Bessant 2013).

Therefore, SEE can be used to evaluate the overall software engineering capabilities of IT vendors from the viewpoint of the following seven factors: deliverables, project management, quality assurance, process improvement, research and development, human resource development, and customer contact. We also introduced two other primary indicators as well: business performance and business environment. Business performance indicates the overall business performance of individual IT vendors, such as profitability, growth, productivity, and efficiency of the management. Business environment expresses the company profile and structure of an IT vendor, e.g., origin of vendor, number of software engineers, average age of employees, business model, customer base, and corporate culture. Business environment complements the relationship between SEE and business performance of software vendors (Kadono 2015a).

Based on the measurement model of SEE survey, we administered it in 2005, 2006, and 2007, together with Japan's Ministry of Economy, Trade and Industry (METI) and Information-Technology Promotion Agency (IPA) (METI and IPA 2007). The questionnaire of SEE on the practice of software engineering and the nature of the responding company was sent to the CEOs of major Japanese IT vendors with over 300 employees, as well as the member firms of the Japan Information Technology Services Industry Association (JISA), and was then distributed to the departments in charge of software engineering.

In the 2005 SEE survey, there were 55 valid responses, a response rate of 24%; and in the 2006 SEE survey, there were 78 valid responses, a response rate of 15%. In the 2007 SEE survey, responses were received from 117 companies, with a total of 100 valid responses, a response rate of 10%. Although the responses are limited compared with the total IT vendors in Japan, the number of software engineers and programmers who belong to the responding companies accounts for over 30% of the total number of them in Japan according to the report published by JISA (JISA 2011). Therefore, the SEE survey results are precious pieces of information in the study of the Japanese software industry at that time.

We observed several salient phenomena in Japan's information service industry from the SEE surveys. For example, one of the SEE questionnaires used to measure human resource development asks about the number of training hours for new recruits. For new recruits, the median is over 400 training hours per year, whereas for other experienced software engineers, another human resource development measurement item queried in the survey, the median is almost 40 training hours per year. This tendency observed in the 2007 survey results was also observed in the 2005 and 2006 results. Manufacturer spin-off vendors tend to invest relatively more time training engineers than do other types of vendors. This trend does not change even now and again.

This is why most IT vendors hire new recruits from universities and graduate schools every year, but many of them have not majored in computer science or software engineering and seem underqualified. In fact, most Japanese software engineers acquire practical skills through on-the-job training in projects but tend to have limited opportunities to formally acquire professional skills based on computer science and software engineering disciplines. In other words, these results suggest that all types of vendors do not rely on the universities in Japan for the software engineering education.

In contrast, in the United States, software engineering and computer science are scientific disciplines that develop the knowledge required for creating software professionally in the horizontally integrated software industry. Therefore, the United States provides sources of information on software engineering and computer science disciplines, e.g., SWEBOK, CMMI, and PMBOK.

8.4 Statistical Analyses

The objective of the research is to better understand the mechanisms of how software engineering capabilities relate to firms' business performance and business environment for the Japanese software industry. Based on the SEE survey results in the previous section, statistical analysis results were demonstrated using structural equation model (Bollen 1989), cross-section analysis, path analysis, stratified analysis, panel analysis, and longitudinal analysis.

First of all, in order to develop a base model, i.e., common causal relationships among the seven SEE factors and business performance, we conducted the interviews with IT vendors and experts in Japan and the United States. And, we identified three key factors for successful innovations: sales force management, operational improvement, and R&D. Some vendors who manage their sales force effectively succeed in efficiently assigning their software engineers to upcoming customer projects. As a result, one such vendor operates at an average of 90% capacity. Other profitable vendors have accumulated data on quality, cost, delivery, and productivity for more than 30 years in order to improve their operations, i.e., kaizen (Ohno 1988). Most large-scale system integrators in Japan work earnestly on R&D activities, in addition to doing effective sales force management and efficiently improving their operations. These three key factors are considered to be innovations in service, process, and product, respectively (Dodgson et al. 2008; Tidd and Bessant 2013).

Second, we conducted literature searches relating to innovation. The manufacturing capability model (Fujimoto 2003) for the automobile industry suggests that organizational routines finally influence business performance through both deep competitiveness, e.g., quality, productivity, product, and development lead time, and superficial competitiveness, e.g., cost, delivery time, and product appeal power. Therefore, we considered the order effect on the three innovation paths in the structural model: IT vendor's routines and deep competitiveness, e.g., from project management to customer contact and from quality assurance to process improvement; superficial competitiveness, i.e., deliverables; and business performance, i.e., operating profit ratio.

As shown in Fig. 8.3, we assume the structural model hypothesis, proceeding from improved human resources development through refinement of deliverables toward improvement in business performance by leverage from the following three types of innovation in the management of software engineering (Kadono 2015a, b):

- Service innovation: proceeding from human resource development to project management and customer contact, as shown in the upper level
- Product innovation: proceeding from human resource development to research and development, as shown in the middle level
- Process innovation: proceeding from human resource development to quality assurance and process improvement, as shown in the lower level

In order to analyze the relationships among SEE, business performance, and business environment from multiple perspectives, we integrated the 233 valid responses received over the 3 years at SEE surveys into a database including 151 unique companies consisting of 42 manufacturer spin-off vendors, 33 user spin-off vendors, and 76 independent vendors. Then we performed several statistical analyses upon the standardized software engineering capability scores for the 3 years and the financial data for 10 years, such as path analysis, cross-section analysis, panel analysis, longitudinal analysis, and stratified analysis.

Regarding the statistical analysis results, first, through the cross-section analysis on the causal relationships among the seven SEE factors and business performance for the 2007 SEE survey, we reproducibly observe that a higher effort level on

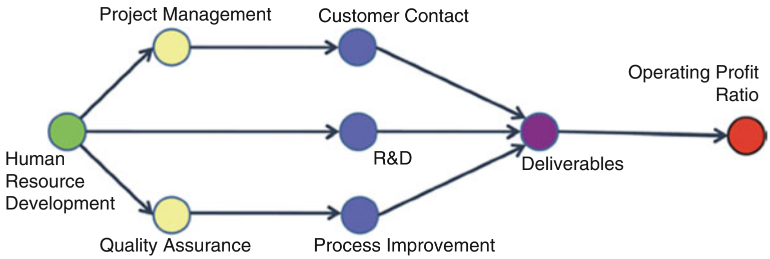

Fig. 8.3 Structural model hypothesis

human resource development, quality assurance, and project management brings about better performance in customer contact, research and development, process improvement, and deliverables; this was consistent with the 2006 survey results. Focusing on management of software engineering innovation, the common order effects originating with human resource development along the paths of service innovation, product innovation, and process innovation were empirically verified based on the data-centric approach (Kadono et al. 2008).

Second, based on the panel analysis of the seven SEE factors, several series correlations among the software engineering capabilities were proved as follows (Kadono et al. 2010a):

- Most SEE factors in 1 year had significant positive influences on the same factor the next year.
- Within a year, there were three paths to improving the level of deliverables, i.e., through project management, quality assurance, and research and development.
- Some SEE factors exerted significant positive influence on different SEE factors in the following year diagonally.
- There were some negative paths, implying that effort put toward a particular factor did not pay off.

These results suggest that each IT vendor needs to know its own nature based on the path dependence and make the most of what it has.

Third, the longitudinal analysis based on the latent growth model suggested positive relationships among software engineering capabilities and profitability, as a component of, and representing, business performance, in software vendors in the drastically changing IT industry in Japan. Based on the panel analysis of the 3-year SEE data and 10-year operating profit ratios of the 151 respondents to the SEE surveys, we significantly verified that IT firms that have excellent software engineering capabilities tend to maintain and improve their business performance in the medium and long term. Equally, the series correlations of a firm's financial performance were observed to correspond to those of its software engineering capabilities (Kadono and Tsubaki 2012).

Regarding implications for technological innovation and industry policy, these results imply the following contemporary perspectives on technological innovation and industry policy (Hasegawa 2013). Based on the longitudinal analysis, we verified that there are significant positive relationships between the sophistication of software engineering capabilities and the superior performance of IT vendors in the long term. At the same time, through the panel analysis of the seven SEE factors, several series correlations among the software engineering capabilities were proved. For example, most SEE factors in 1 year had significant positive influences on the same factor the next year. It follows that the structure of the software engineering capabilities and the financial results of IT vendors should be considered to be entrenched in the long term (Kadono 2015a).

On the other hand, the relationships among the seven SEE factors and business performance vary significantly depending on the origin of a vendor: manufacturer spin-off, user spin-off, or independent. If we focus on the management of innovation, then, in manufacturer spin-off vendors, service innovation, process innovation, and product innovation are effectively connected. However, in user spin-off vendors, any indicated software engineering innovation is attributable to a management policy of paying extra attention to business performance. In independent vendors, human resource development is the only factor that positively and significantly influences the other capabilities and business performance (Kadono 2013). Also, having regard to the size of vendors, we found that vendors who have a larger number of software engineers tend to get a higher SEE score (METI and IPA 2007).

We also investigated the characteristic differences among manufacturer spin-offs, user spin-offs, and independent vendors. The objectives of this research are to describe the competitive environment in the software industry in Japan and to understand the characteristic differences among the types of vendors. Based on management frameworks such as Porter's five forces (Porter 1980) and Barney's resource-based view (Barney 2007), we developed a model to measure environmental threats and competitive strengths/weaknesses. We then conducted factor analysis of the data collected from 100 major IT vendors in Japan.

On this basis, we extracted eight threat factors, e.g., industry stagnation, difficulty in recruiting bright people, ROI/quality demands from clients, price cutting/quick delivery demands from clients, and adoption of new technology. We also identified six strength/weakness factors, e.g., human capital, advantage of scale, expansive business, inimitability, and stability. Regression tree analysis suggested that manufacturer spin-off vendors tend to significantly expand their business with well-resourced R&D, while user spin-off vendors seem to depend heavily on demand from parent companies, as a result of which some of them are thought to gain inimitable capabilities. On the other hand, many small- and medium-sized independent vendors supply temporary staff to principal contractors and do not show specific strengths; even so, some independent vendors with inimitable assets are thought to be role models for software vendors in Japan (Kadono et al. 2009).

From the above statistical analysis results, in formulating industry policy proposals to promote software engineering innovation, we should consider both the individual characteristics and the organizational inertia, broken down by type of vendor, e.g., scale and innovation adoption. For example, the government should encourage manufacturer spin-off vendors, especially large-scale system integrators, to accelerate state-of-the-art product innovations; to this end, the government should commission huge nationwide IT projects. On the other hand, the government should financially support small- or medium-sized independent vendors to help them develop human resources in software engineering. To help shape sound industry policy, we think it is crucial that:

- A stable measurement tool be established, such as the SEE survey, by which to measure the management of innovation in the software industry in Japan
- Financial reporting standards be adopted in common by corporate managers (Kadono 2015b)

In terms of limitations of a series of the statistical analysis, since the SEE surveys were a large-scale and costly research method, it was not practical to continue administering the surveys routinely, year after year. Therefore, we integrated the 233 valid responses received over the 3 years, 2005 through 2007, into a database including 151 unique companies, the better to perform several statistical analyses, such as a longitudinal analysis of the relationships between the SEE scores and the financial data from 1999 through 2008. We proved several findings that are statistically significant; however, the amount of the SEE data is not necessarily sufficient to perform some other statistical analyses that would be desirable, e.g., stratified analysis of the SEE scores by type of vendor for any given year.

Although the research in this paper is intended to cover issues relating to IT management and software engineering innovation in the broadest sense, the research approach—using social surveys and statistical analyses based on the resource-based view—has limitations. For example, if the rules of the game in the Japanese software industry change in a rapid and unpredictable manner, e.g., Schumpeterian revolutions, or a paradigm shift caused by a breakthrough in technology, then it will be difficult to adapt the findings discovered by the approach to a new business environment (Kadono 2015a).

8.5 Simulations

Regarding simulation research and IS research, simulation research has always been controversial primarily due to lack of understanding its role. Even strategy and management literature have debated and accepted the role of simulation in theory building. Therefore, simulation is perhaps the most appropriate methodology in the following situations (Davis et al. 2007):

- Theoretical focus is longitudinal or futuristic.
- Relationship between constructs is nonlinear.
- Focus of research is process discovery, process improvement, or process control.
- Empirical data are challenging to obtain.

Considering these remarks, in order to model the current and future structure of the software industry in Japan, we developed an agent-based simulation model that was an extension of the Sugarscape model (Epstein and Axtell 1996; Yamakage 2007; Kadono and Terano 2002). Based on statistical analysis results in the previous section, it was implicated that software vendors in Japan are mainly characterized by their scale and innovation adoption: big software vendors, e.g., system integrators, medium-sized technology-oriented vendors, medium-sized sales-oriented vendors, and small subcontractors.

Therefore, the model consisted of software vendors with varied scale, readiness to innovate, and outsourcing ratios. In the model, we assumed that the market would follow the same cycle of technology innovation as for mainframe computers, client servers, Web applications, cloud computing services, and so on and that the larger software vendors would tend to invest more in innovative technology and outsource more jobs to the smaller software vendors in a multilayer industry structure (Kadono et al. 2010b).

For the investigation, we set the following three scenarios. In each scenario, we continued to apply the conditions and parameters of availability within the agent-based simulation model.

- Survival by size and skill: The big software vendors grow increasingly, thanks to their resourceful staff and skills, exploiting their advantages of scale and scope, whereas the small- and medium-sized software vendors do not survive unless they can catch up with rapid technology innovation. As a result, the software industry structure in Japan eventually consists of a smaller number of vendors, each with distinct scale or special skills.
- Reciprocal relationships: All current types of market participant survive, thanks to the outsourcing of jobs from big (or medium-sized) software vendors to medium-sized (or small) software vendors in the current multilayer industry structure. In particular, small software vendors do not survive without outsourcing from the big (or medium-sized) vendors.
- Reverse phenomena: Some medium-sized technology-oriented vendors outpace big software vendors who tend not to invest as much in innovative technology.

Based on the above scenarios, we suggested that future studies be conducted on the following: interactive behaviors among software vendors, e.g., project-based alliances, and merger and acquisition (M&A), effects of offshore development, and effects of new participants in the Japanese software industry.

8.6 New Research Topics Through Integrated Approach

We have been extending the scope of integrated research approach (Kadono 2015b) toward the customer in Fig. 8.1. Although the customer is classified as a business customer and an individual customer, i.e., a consumer, we are currently promoting research on Electronic Commerce (EC) of Business to Consumer (BtoC) in ASEAN countries, e.g., Indonesia, Vietnam, and Thailand.

Regarding the academic background of EC diffusion, the context of EC success factor research overlaps with the genealogy of technical acceptance research and spreads to the world mainly from the developed countries of ICT, i.e., the United States, since around 1990.

First, as a genealogy of technology acceptance research, technology acceptance model (TAM) (Davis et al. 1989) and the unified theory of acceptance and use of technology (UTAUT) (Venkatesh et al. 2003) on employee's technology acceptance in organization have been developed as the source of technology acceptance research. In response to personalization of ICT utilization, it has been extended to acceptance of technology for consumer subjects (UTAUT2) (Venkatesh et al. 2012). The main constructs are perceived usefulness and perceived ease of use in TAM. UTAUT takes into consideration performance expectancy, effort expectancy, social influence, and facilitating conditions. UTAUT 2 has new constructs, such as hedonic motivation, price value, and habits.

Second, the research on EC success factors has increasingly focused on trust and customer value on the process of personalizing ICT and establishing a new purchasing style in the mobile era. In the constructs of trust, safety, reliability, availability, security, and legal framework are considered (Jones et al. 2000). And, EC vendors are evaluated by perceived reputation, trusting beliefs, and so on (McKnight et al. 2002). The causal structure analysis from system trust, perceived trust, to purchase intent lead to purchase intention was performed (Pennington et al. 2003).

Concerning customer value, the constructs such as brand (Brynjolfsson and Smith 2000), perceived usefulness, and ease of use (Ahn et al. 2004) are extracted. Based mainly on the findings from EC developed countries, research on EC diffusion process related to trust and customer value in the world has been conducted widely in the world (Ba and Pavlou 2002; Hayashi and Higa 2009; Azam et al. 2012). Since the elucidation of problem structure peculiar to emerging countries is increasingly expected at the expanding phase of EC market in ASEAN, we are trying to use the integrated approach of issue, survey, statistics, and simulation, to this topic (Alfanur and Kadono 2017; Masuoka and Kadono 2018).

8.7 Conclusions

This paper investigates the potential to predict future scenarios in the Japanese software industry through an integrated approach of data obtained from issue-oriented large-scale fact-finding investigations, statistical analyses based on dynamic modeling, and simulation of future scenarios.

This endeavor should be significant both as academic research and in its practical implications, as follows:

- First, by integrating large-scale surveys, statistical analyses, and future prospects, we suggest guidelines for a global technology strategy for the industry, with a view to obtaining sustainable competitive advantage.
- Second, the research throws up a significant challenge: it should be possible to develop evidence-based visualization of industry growth scenarios by integrating intellectual instruments that have hitherto evolved separately, such as fact-finding surveys (as conducted by METI and IPA); management theory, including resource-based views, competitive threats, and diverse competitive advantages of diverse nations; statistical analyses, such as dynamic covariance modeling; and social simulation models.
- Third, methods can perhaps be developed to design plans for the management of technology as a national strategy, through visualization of a variety of scenarios, ranging from optimistic to pessimistic. We do not aspire to predict future scenarios precisely but aim for a deeper understanding of the complex and multifaceted issues to be managed by policymakers and leading companies.

We would like to extend our research in the field of Japan's information service industry and EC in ASEAN to do broad work in the future since the method, which integrates large-scale surveys, statistical analyses, and future prospects, has potential to be expanded and generalized to illuminate any industrial sector in any country.

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Chapter 9
U-Mart: 20-Year Experience of an Artificial Market Study

Hajime Kita

Abstract The U-Mart is a collaborative study in artificial markets by economists and computer scientists. Since its start in 1998, the study has continued for 20 years. Design and development of an artificial market system also named U-Mart is the central activity in this study. From the beginning, it aimed to provide the artificial market a testbed for studies in financial markets and considered to model actual mechanism of real markets. With its hybrid design of agent-based simulation and gaming simulation, it is effectively used for education as well as research. This paper shows the experience of 20-year study of the artificial market and discusses its future.

9.1 Overview of the 20-Year Activity

In 1998, Dr. Yoshinori Shiozawa, an economist proposed to several computer scientists to develop an artificial market system for experimental study of economics. It was inspired by the RoboCup[1] in the field of artificial intelligence and robotics which had started several years before. Responding his proposal, the study of the U-Mart started discussion in that year, and in 1999, the research group started the development of the artificial futures market.

The first implementation of the system was released in spring 2000, and with the developed system, the first open experiment for trading by agents was carried out as "Pre U-Mart 2000," in this summer. After several experiences of using the U-Mart for open experiments and education both in economics and computer science, the research group revised the system.

[1] http://www.robocup.org/ (Last access Feb. 20, 2018)

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The revised system called U-Mart Version 2 was released as a stable and comprehensive version of the U-Mart (Shozawa et al. 2008). Up to this version, U-Mart employed “Itayose” method for order matching. This method was used in limited scenes in actual financial markets, but we employed it because it was rather easy to understand and easy to implement as a computer program.

Then, the research group started to create a next version of the U-Mart seeking simulation of more realistic financial markets. It employed “Zaraba” method, a continuous double auction which was actually used in exchange markets such as the Tokyo Stock Exchange (TSE). However, the development of the Zaraba version was much more difficult than the previous “Itayose” version because of its real-time nature and necessity of implementing various institutional devices employed in the actual markets (Kita et al. 2016).

Development of the system has been the central activity of the research group, and the developed systems were used intensively as course material for hands-on study of financial markets. Along with that, the research group also conducted study on the markets using the U-Mart. For example, the group studied the institutional design to encourage trading with market makers for thin markets.

9.2 The Third Paradigm of Scientific Research

Behind the proposal of making an artificial market by Shiozawa, there was an intention to open computational approaches as “the third paradigm of scientific research” (Chapter 1 of Kita et al. 2016) in economics or more widely in social sciences.

Theory and experiments were two major methodologies in scientific research. Along with the progress of information technologies, computational approaches have emerged. That is, to use computer simulation instead of experiments. Nowadays, computational approaches are taken commonly in natural science and engineering.

However, to apply it to the social sciences has some difficulties. Of course, there have been studied models of differential equation types in such fields. However, meaning of equations is quite different in natural science and in social sciences. In natural science, fundamental equations are described as differential equations, and systems of interest are usually rather symmetric. Hence models of differential equation type are well grounded. Contrary to this, social sciences have to treat behaviors of humans in societies, and a human itself is a very complex system. Further, humans behave under restriction of various social systems in societies. Hence, meaning of models using differential equations in social sciences is not well grounded. Another important framework in social sciences is assumption of rationality of human. That is, model of human as a maximizer of his/her utility function is used assuming rationality. However, it is also not well grounded. While boundedness of rationality has been proposed as a criticism on it, alternative framework has not been established well.

The agent-based approach can be expected as a promising way for modeling and simulation of social systems. This approach directly treats humans as individual agents in a society rather than using aggregated values of the population. The agent's behavior described by a computer program can take bounded rationality into consideration in various forms such as routine, optimization, adaptation, or learning. Shiozawa's proposal of the U-Mart was to start such a new way of research in the field of market economy. Terano, one of the founders of the U-Mart study, called the U-Mart as "the Smallest Big Project in the World" considering its characteristics in Chapter 4 of Kita et al. (2016). That is, while the U-Mart has been activities of small number of researchers, it developed a common platform for a new academic field through interdisciplinary collaboration for many years, which is a characteristics of big projects.

9.3 Pursuing Facsimile Model of Financial Market

Gilbert categorized agent-based models into the following three from a viewpoint of model validation (Gilbert 2008):

- Abstract models
- Middle-range models
- Facsimile models

Artificial markets, agent-based models of market, can be also categorized along this classification.

To study fundamental natures of market economy, such as dynamics and statistics of price formation in markets, and raise and collapse of bubbles, rather simple models of the abstract type will be effective. A pioneer work in artificial markets by Arthur et al. (1996) can be categorized into an abstract model.

However, to discuss control of market through institutional design, more realistic models of the facsimile type are needed. The U-Mart has aimed at usage of the artificial market for evaluation and design of institutional matters of financial markets, and therefore it has been developed as a model of the facsimile type. Koyama discussed this issue calling U-Mart as "a second generation artificial market" (Koyama 2008). In design of U-Mart, Ono and Sato proposed "fidelity," "transparency," "reproducibility," "traceability," and "usability" as requirements to the realistic artificial markets in Chapter 3 of Kita et al. (2016).

9.4 Design of Artificial Market

The artificial market system U-Mart has several design features as follows:

9.4.1 Purposes of System Design

The U-Mart was developed for the following purposes:

- To provide an open testbed for market study with the agent-based approach for academic research and education. That is, with the U-Mart, researchers and learners can freely use the system for study along their interests.
- To examine institutional issues of financial markets. Actual financial markets employ various institutional devices for order matching, alternation of prices, limitation of trading, etc. so as to encourage trading and to stabilize the market. They are design issues of financial markets so as to achieve its function so as to contribute to the society. We are interested in study of such design issues as a way of using artificial markets.

9.4.2 Futures: Grounding of Artificial Market

In the development of the artificial market system, we have to solve a fundamental problem of what is dealt in the artificial market and how can we ground it to reality.

If we deal completely virtual things in the artificial market, no agent can assess its proper price. Contrary to this, if we deal things treated in a real market, we have no freedom of making a price in the artificial market. To solve this problem, Shiozawa proposed to deal with futures of an existing stock index in the artificial market. That is, prices of the existing spot market of the stock index are fed into the artificial market exogenously, and in the artificial market, referring the spot price of the index, the agents trade its futures. In the due date, settlement of futures is carried out referring the spot price.

While this scheme is simple, it restricts the behavior of the agent through consideration of settlement in the due date. Further, the agent can use information of spot prices as well as those of futures, and it allows various trading strategies for the agents.

9.4.3 Order Matching and Other Institutional Issues

The U-Mart was designed aiming at computational study of institutional design of markets. A method for order matching is one of such issues.

“Itayose” and “Zaraba” are Japanese words of order matching methods used in Japanese stock exchange markets. In “Itayose” method, buying or selling orders submitted to the market are stored in a prescribed period, and then, the market finds the matching of orders and a contract price that maximize contract volume among the submitted orders. It is used, for example, at the start of the market in TSE. In other words, it decides the volume and the price at the cross point of the aggregated buying order (a demand curve) and the aggregated selling order (a supply curve). Up to Version 2, the U-Mart employed the "Itayose" method because it was easy to understand by users and easy to implement as a computer program.

"Zaraba" is an order matching method of a continuous time double auction type. It is employed as the main method in TSE. In Zaraba method, submitted orders are shown to all the traders, and if an order that matches to the listed order(s) is submitted, they are contracted immediately. Thus, Zaraba has a real-time nature, and several institutional options to control the behavior of the market are also introduced. Thus, it makes development of both a market exchange server and trading agents difficult. In the U-Mart Version 4, we implemented the Zaraba method in the system for more realistic simulation of the market.

9.4.4 Hybrid of Agent-Based Simulation and Gaming Simulation

From the beginning, the U-Mart considered both humans and software agents as traders in the artificial market. In other words, the U-Mart is designed as a hybrid environment for agent-based simulation and gaming simulation. It gives the system several advantages. For example, the U-Mart can be used for hands-on gaming simulation for courses in economics. Even with the small number of players, they can play trading with software agents as well as the other human players. In the development of the trading software agents, the programmers can easily understand the artificial market with gaming. That is, programmers can understand the market system having complex configuration not only through the specification document but also through playing the game by themselves.

9.5 Implementation Strategies

Through our experiences of the study in the early stages, we took the following implementation strategies in the U-Mart.

9.5.1 Server-Client Architecture with Session-Oriented Protocol

In implementing a hybrid simulator for both agent-based simulation and gaming simulation, we had to design an exchange market model, human interface to play games, and interfaces for trading software agents. So as to implement such a system efficiently, we first designed a trading protocol named SVMP (simple virtual market protocol) as a session-oriented and text-based protocol.[2]

Then, using SVMP as an interface connecting the market server and the traders (human or software agents), we implemented the system using server-client architecture. Thus, we could develop the market server and the user interface for trading independently.

Currently, the U-Mart system is packaged as an all-in-one system, but inside it, GUIs for manual trading and management of the market and the engine of market server are implemented as modules, and thus we can maintain them independently.

As for implementation of the software trading agents, we can implement trading clients via SVMP. However, it is not efficient both in development of agents and execution of the market simulation using such agents. Hence, we defined classes for trading strategies or trading agents, and they were built into the U-Mart server referring the configuration file describing such classes. It enabled flexible and efficient experiments of market simulation. For dynamic setup of software agents using a configuration file, we used the "reflection" function of Java language.

9.5.2 Platform Independence

In interdisciplinary study of artificial market, we have to consider simulation platform both for economists and computer scientists. They use various computing platforms such as Linux, Windows, and Mac. So as to make interdisciplinary collaboration easy, we developed the U-Mart as a platform-independent application. That is, U-Mart is written only in Java which can work in every aforesaid computing platforms. Internationalization to use the system both in Japanese and English was also considered and implemented using the internationalization framework of Java.

9.5.3 In-Memory Data Handling

Through the experience of the U-Mart in early days, we found usages of the U-Mart in gaming for 1–2 h or intensive computer simulation only with software agents were rather useful than its real-time operation with the actual stock market in parallel feeding its price information as that of the underlying asset. Usual information systems that serve over a network use a database management system (DBMS) for reliable handling of data under accesses by multiple users in parallel.

[2]In this sense, it is similar to protocols such as POP (post office protocol) for e-mail. These days, WWW is used for most of the information systems, but the basic design of http, a protocol used for WWW, is session less. So as to achieve session-oriented communication over WWW, various additional techniques are used.

However, considering aforesaid usages of the U-Mart, we have to achieve fast data processing with ordinary personal computers. Hence, we adopt in-memory data handling without DBMS.

With this design, the U-Mart could be operated in gaming of several tens of players only with an ordinary personal computer as a market server. As for usability, it made operation of the U-Mart easy for all the participated researchers and their students both in economics and computer scientists.

9.5.4 Object-Oriented Design

So as to implement complicated functions of the market server including various institutional matters, and concurrent processing of sessions from the multiple client traders, we employed object-oriented design of the system. The system is implemented in Java, considering aforesaid platform independence, object-oriented programming, and performance of execution in large-scale gaming and intensive agent-based simulation.

9.5.5 Data Format Considering Spreadsheet

In setup of market simulation both in gaming and agent-based simulation, we need to specify several parameters for each simulation run. After simulation, we have to analyze the result referring log files yielded by the U-Mart. So as to make setup and analysis of the simulation easy both for computer scientists and economists, we adopt CSV file format both all for setup files and execution log files. Thus, with spreadsheet software, the user can easily setup simulation and examine the simulation results.

9.5.6 Standard Agent Set

In the U-Mart, a software agent has to make orders including:

- An order type of “Buy,” “Sell,” or “None.”
- A limit price to avoid a contract in low price in selling and high price in buying.
- A maximum volume of the asset to buy or to sell

The order should be decided by the agent referring previous price series both of spot market and futures so as to assess trading opportunities and referring its position and available amount of cash to control its risk.

As well as the exchange market server and GUI-based trading terminal for human players, we also provided the standard agent set implementing various trading strategies. It aimed:

- To provide a hands-on simulation environment without developing any software agents.
- To show example implementation to guide development of software agents by users.

It includes simple agent that decides orders randomly, agents of trend chaser and anti-trend chaser types, agents using index named RSI, agents referring price spread between spot and futures prices, agents using the moving averages of the prices with different time windows, and agents which submit buying and selling orders simultaneously.

9.5.7 Stable Versions

Up to now, we have developed the following two versions of the U-Mart as stable versions:

- U-Mart Version 2, an Itayose-based system
- U-Mart Version 4, a Zaraba-based system

The U-Mart Version 1 and 3 were experimental ones for trial implementation of Itayose and Zaraba U-Mart systems. Technical aspects of implementation such as computational models of the markets and object design of the systems are explained in Ono et al. (2008) and Kita et al. (2016) (Chap. 3).

9.6 Education and Research Using U-Mart

9.6.1 Experimental Studies Using Hybrid Simulation

The U-Mart system was designed to support gaming simulation played by human as well as agent-based simulation, and it has been used as a teaching tool of financial market. The learners can understand various aspects of the market through hands-on experience of playing in the artificial market. At the same time, such experiences of using the U-Mart system in education were fed back to the development of the system. For example, gaming was a tough test for the market server because the real-time access by multiple users playing seriously was a difficult task for the system in processing concurrent sessions connected by the users. As for the client side, usability of GUI was largely improved through the experience of using the U-Mart in education.

Gaming with the U-Mart also gave some insights of human behavior in the market. Taniguchi reported the behavior of gaming using the U-Mart in Chapter 8 of Kita et al. (2016). Taniguchi et al. also discussed difference in Itayose and Zaraba through human play in gaming (Taniguchi et al. 2008). Yamada et al. discussed behavior of the market with software agents as well as human play in gaming (Yamada et al. 2008). Matsui and Ohyama studied optimal execution of orders in the financial market experimentally using the U-Mart in Chapter 7 of Kita et al. (2016).

9.6.2 Study of Market Makers for Thin Markets as an Institutional Design

Study of institutional design for financial markets is one of the purposes of our study. Stock exchange markets such as TSE employ order-driven market. That is, market shows information of orders submitted by the traders, and traders submit their orders examining information of orders listed in the market. In trading stocks of large companies, many orders for selling and buying gathers to the market. In other words, the market is *thick*. In such thick markets, the trader can easily make orders that can be contracted in short time. That is, the order-driven systems work well in thick markets.

However, if we extend markets to treat stocks of small and regional companies, number of traders who wants to buy or sell the stocks of each company becomes small. Then, with the order-driven system, it gets difficult to find an adequate price for matching and to contract orders only with those submitted by the traders. It is a problem in *thin* markets.

The U-Mart study group also discussed institutional design for such thin markets (Nakajima and Shozawa 2004; Matsunaga and Kita 2006; Kita et al. 2006) and in Chapter 6 of Kita et al. (2016). For such thin market, introduction of market makers and to make the market a quote-driven type will be a candidate solution to encourage trading. The market makers play as brokers by always showing their buy and sell orders with prices in the market. The ordinary traders can know the prices of the items and can execute their orders to some extent by matching orders by the market makers. Thus, the market makers supply liquidity to the thin markets. However, to introduce market makers, we have to confirm its feasibility because the market makers are obliged to put orders to the market, and their risk of yielding loss should be well controlled.

In Chapter 8 of Kita et al. (2016), Nakajima studied possibility of introducing market makers from the aforesaid point of view. He studied feasibility of market makers of several models. Such models are tested with agent-based simulation and gaming simulation using the U-Mart Version 2.

9.7 Toward Realistic Simulation of Financial Markets

During these two decades, financial markets themselves have changed largely due to progress of information and communication technologies. Nowadays, some exchange markets process orders in very short time, and computer programs are commonly used for automatic trading in such markets. It is called HFT (high-frequency trading). Furthermore, progress in technology brings about another new scientific research paradigm, i.e., data science (Hey et al. 2009). Application of artificial intelligence to market economy gets also an important issue.

In such situation, importance of artificial markets becomes larger as a tool for experimental study of markets. In the U-Mart, we have mainly investigated development of a realistic artificial market system. However, so as to simulate markets, we need a comprehensive set of tools such as:

- Exchange market simulator(s) to treat multiple markets and multiple items to simulate a set of trading opportunities
- Various trading strategies that treat in multiple items considering their asset portfolios
- Data analysis methods to examine data from actual markets and those from simulation with artificial markets
- Adaptation, learning, and evolution algorithms for trading strategies. In the U-Mart study group, Mori et al. have applied genetic programming to the design of trading agent in Chapter 5 of Kita et al. (2016).

Placing the developed U-Mart system as a core tool, we would like to continue our study toward realistic simulation of financial markets.

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Chapter 10
What Do Agents Recognize? From Social Dynamics to Educational Experiments

Masaaki Kunigami

Abstract This is an overview of recent developments in agent's cognition modeling, simulation, and experimental observation. These focus on what agents recognize and on the differences between agents. On modeling and simulation, we introduce a new formulation called the Doubly Structural Network (DSN) model and show its applications in socioeconomics and education. The DSN model is a useful framework to describe the dissemination process of innovative recognition. On experimental observation, we look at two educational applications called the Pictogram Network (Pict-Net) Abstraction and the Persona Design Method.

10.1 Introduction

This is a short brief on recent progress in agent-based model simulation and experiments. Here we focus on the agents' cognition from two aspects. One is how we formalize the agents' cognition and another is how we observe them. Both approaches help us to find novel implications and applications.

To address the first aspect, formalization, Sect. 10.2 introduces an approach to describe interacting agents that is called the Doubly Structural Network (DSN) model. The DSN model represents both the agents' interaction via an interagent network and the internal transformation of their semantic networks. Initially, the DSN model was developed for economic and social research, but it is now also applied in educational studies.

For the second aspect, observation, Sect. 10.3 introduces two interesting experimental approaches for education: one is the Pictogram approach to visualize the agents' semantic network and the other is Persona approach to quantify the agents' potential attitude. These two approaches enable us to observe and compare agent intention or understanding in different situations.

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10.2 Modeling and Simulation: Doubly Structural Network Model

We are going to overview several socioeconomic and educational studies with dynamical modeling and agent simulation. These studies are based on our individual style of modeling formulation named the Doubly Structural Network (DSN) model. After the introduction of the DSN model formulation, we outline the applications to socioeconomics and education.

10.2.1 Formulation of the Doubly Structural Network (DSN) Model

Different from other agent-based modeling (Axelrod 1997) (Epstein and Axtell 1999) or network modeling (Epstein and Axtell 1999; Masuda and Konno 2006; Pastor-Satorras and Vespignani 2002) approaches, the DSN model has a double structure of an interagent network and internal-agent networks. The interagent network represents agent-agent connections such as social, economic, or organizational interaction. In contrast, each inner network of the agents describes a semantic network structure of an individual agent's recognition, awareness, and knowledge. Therefore, the double structure of networks is convenient to formalize and analyze the emergence of common knowledge or collective recognitions in a group or society.

Kunigami et al. (2009, 2010a, b) defined the mathematical formulation of the DSN model as follows (Fig. 10.1).

$$\left(\begin{array}{ll} G^S \equiv \left(V^S, E^S\right), V^S \equiv \left\{v_i^S \,|i = 1 \sim N\right\}, E^S \subseteq V^S \times V^S & \text{(a)} \\ G_i^I \equiv \left(V^I, E_i^I\right), V^I \equiv \left\{v_\alpha^I \,|\alpha = 1 \sim M\right\}, E_i^I \subseteq V^I \times V^I & \text{(b)} \\ G^D \equiv \left\{\left\{\left(v_i^S, G_i^I\right) |i = 1 \sim N\right\}, E^S\right\} & \text{(c)} \\ G_{t+dt}^D \equiv F\left(t, G_t^D\right) & \text{(d)} \end{array}\right. \qquad (10.1)$$

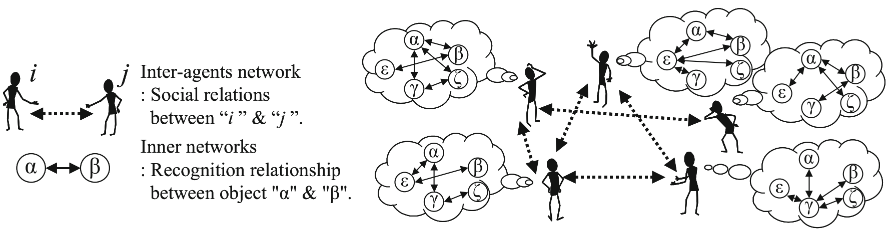

Fig. 10.1 A doubly structural network (DNS) model of society (Kunigami et al. 2009, 2010a, b). This model consists of an interagent network and inner-agent networks. The interagent network relates to the interaction among agents, and each inner-agent network represents recognition of an individual agent

- In formula (10.1a), "social (interagent) network" G^S represents the social relationship between agents. The node (vertex) $v^S{}_i$ represents the i-th agent. The edge set E^S represents social connection between these agents.
- In formula (10.1b), each "inner/internal (recognition) network" $G^I{}_i$ represents the internal landscape or recognition of the i-th agent on certain objects (α, β, . . .). The node (vertex) $v^I{}_\alpha$ represents the object α. The edge set $E^I{}_i$ represents the semantic connection between those objects in the i-th agent's recognition.

(Whichever directed/undirected graph is available for social or internal network.)

- Formula (10.1c) shows that the "doubly structural network" G^D is created by attaching (mounting) each inner/internal (recognition) network $G^I{}_i$ ($i = 1,2, \ldots ,N$) onto the corresponding node i (ith agent) of the social (interagent) network G^S.
- Formula (10.1d) shows that a propagation/learning model of the doubly structural network is defined by the changing states (connection/disconnection) of the agents' internal networks via interaction of the agents in the social network.

This structure has the following advantages:

- To directly describe the states of the recognition of the inner network by its own shape
- To define the autonomous/intrinsic evolution of the inner networks related to its own shape
- To describe the micro/macro interaction related with agents' internal evolutions

Next, to apply the DSN model to a particular social, economic, or educational problem, we need to implement the characteristic mechanism into both interagent and internal-agent interactions.

10.2.2 Emergence of Money: A Socioeconomic Application of the Doubly Structural Network (DSN) Model

Here we present an example of DSN model application as seen in Kunigami et al. (2009), Kobayashi et al. (2009a), and Kunigami et al. (2010a, b). The problem is a well-known economic problem known as the "emergence of money." Using a differential equations model and simulation model, we found that some characteristics of the social network were a key factor in the bifurcation phenomena on the emergence of money.

The implementation of the mechanism to describe the emergence of money is as follows. Upon implementation, the social (interagents) network reflects the topology of economic/social relationships between agents (indicated as $i,j = 1 \sim N$). The agents' inner networks represent their own recognition of the exchangeability between commodities (indicated by $\alpha,\beta,\gamma = 1 \sim M$). Each element of the adjacent

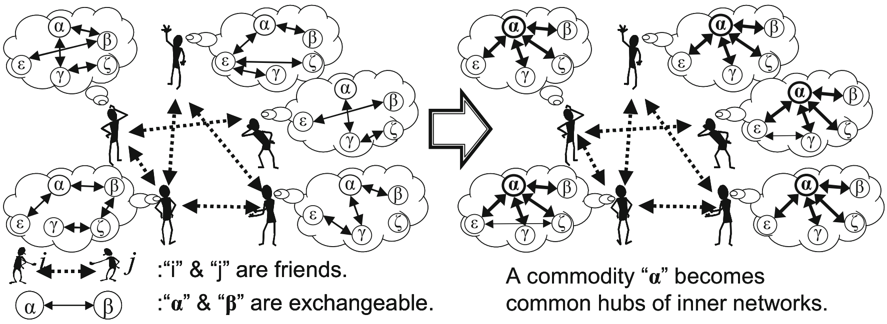

Fig. 10.2 The emergence of proto-money in the Doubly Structural Network Model (Kunigami et al. 2009, 2010a, b). Edges of inner networks represent that the agent recognizes exchangeability between the connected commodities (e.g., "α" and "β"). When a particular commodity (e.g., "α") becomes a hub (exchangeable with almost all the other commodities) in almost all agents' recognition, the commodity ("α") emerges as proto-money

matrix of the i-th agent's inner network is determined as $\mathrm{e}^{(i)}{}_{\alpha\beta} = \mathrm{e}^{(i)}{}_{\beta\alpha} = 1$ if α and β are exchangeable for the ith agent, or as $\mathrm{e}^{(i)}{}_{\alpha\beta} = \mathrm{e}^{(i)}{}_{\beta\alpha} = 0$ if not.

Many economists maintain that money is essentially a medium of exchange (Hayek 1976; Hicks 1967; Menger 1923). For the emergence of money as a medium of exchange, almost all the agents within the society must recognize that this commodity is exchangeable with almost all others. This nature is called "general acceptability." To focus on the most primitive form of money, we define "proto-money" as a commodity that has general acceptability. Therefore, we use "emergence of money" as the emergence of proto-money from a barter economy.

In the DSN model, the emergence of proto-money α is represented as a self-organizing process in which a large proportion of inner networks become similar star-shaped networks (Starr 2003; Yasutomi 1995) with a common hub α (Fig. 10.2).

The agents in this model interact with each other in the following manner during each time step:

- Exchange: In the social (interagent) network, neighboring agents i and j exchange commodities α and β with probability P_E, if both of them recognize that α and β are exchangeable (i.e., $\mathrm{e}^{(i)}{}_{\alpha\beta} = \mathrm{e}^{(j)}{}_{\alpha\beta} = 1$). All exchanges are assumed to be reciprocal.
- Learning: The learning process of the agents consists of the following four methods:
  - Imitation: If an agent i's (let $\mathrm{e}^{(i)}{}_{\alpha\beta} = 0$) neighbor j and j's neighbor j' succeeded in exchanging $\alpha{-}\beta$, then i imitates j (i.e., $\mathrm{e}^{(i)}{}_{\alpha\beta} \rightarrow 1$) with the probability P_I.
  - Trimming: If an agent i has a cycle recognition of exchangeability (e.g., $\mathrm{e}^{(i)}{}_{\alpha\beta} = \mathrm{e}^{(i)}{}_{\beta\gamma} = \mathrm{e}^{(i)}{}_{\gamma\alpha} = 1$), then the agent i will trim its inner network by randomly cutting one of these cyclic edges with the probability P_T to avoid cyclic exchanges.

Two more additional processes representing natural fluctuations are introduced.

– Conceiving: Even if an agent i has no recognition of $\alpha-\beta$ exchangeability ($\mathrm{e}^{(i)}{}_{\alpha\beta} = 0$), it will happen to conceive that ($\mathrm{e}^{(i)}{}_{\alpha\beta} \rightarrow 1$) with the probability P_C.
– Forgetting: Vice versa, even if an agent i has recognition of $\alpha-\beta$ exchangeability ($\mathrm{e}^{(i)}{}_{\alpha\beta} = 1$), it will happen to forget this ($\mathrm{e}^{(i)}{}_{\alpha\beta} \rightarrow 0$) with the probability P_F.

$$\begin{aligned}\frac{dx_{\alpha,k}}{dt} &= P_E P_I \left(1 - x_{\alpha,k}\right) k \left(\frac{\sum_{k'} k'(k'-1)p(k')x_{\alpha,k'}}{\sum_{k'''} k'''p(k''')} \left(\frac{\sum_{k''} k''p(k'')x_{\alpha,k''}}{\sum_{k'''} k'''p(k''')} \right)\right) \\ &\quad - P_T M x_{\alpha,k}^2 \sum_{\beta\neq\alpha} x_{\beta,k} + P_c \left(1 - x_{\alpha,k}\right) - P_F x_{\alpha,k} \qquad (10.2) \\ x_{\alpha,k} &\in [0, 1], \quad \alpha = 1, 2, \ldots, M, k = 1, 2, \ldots, \quad p\left(k'\right) = \text{prob.}\left(k = k'\right).\end{aligned}$$

Equation (10.2) (Kunigami et al. 2009, 2010a, b) is a mean-field differential equations representing the DSN model of the emergence of proto-money. The parameter "k" represents the degree of nodes (agents) on the social network. The degree k is assumed to have a distribution function $p(k)$. The state variable $x_{\alpha;k}$ represents the probability that an agent with social network degree k recognizes exchangeability between α and another arbitrary commodity. The constant M is the total number of the commodity types.

Using the mean-field dynamics of the DSN model (10.2), Kunigami et al. (2009) described a scenario of the emergence of proto-money. In the scenario, even if a commodity "α" has a slight advantage for exchange compared with the other commodity types, the exchangeability of "α" grows more and more, and the growth of exchangeability of the others' is suppressed. This scenario is consistent with the "metallic theory of money," which maintains that a commodity becomes money due to its appropriate attributes for exchange.

In a subsequent study, Kunigami et al. (2010a, b) derived another scenario and a bifurcation phenomenon of the emergence of proto-money. They added "1st–2nd approximation" to the mean-field differential equations. The "1st–2nd approximation" reduces the high-dimensional equation system into a two-dimensional system by focusing on only the commodities that have the largest and second largest exchangeabilities.

Their "1st–2nd mean-field dynamics" derived the following two findings: First, proto-money is able to emerge from commodities that have no particular advantage to others. Next, the emergence of proto-money shows a bifurcation phenomenon depending upon a characteristic of the social (interagent) network.

The first finding "proto-money could emerge from commodities that have no particular advantage" is consistent with the "nonmetallic theory of money." In addition, the finding from the DSN model in Kunigami et al. (2009) was consistent with the "metallic theory of money." Therefore, the both findings imply that the DSN model could possibly integrate "metallic theory" and "nonmetallic theory of money."

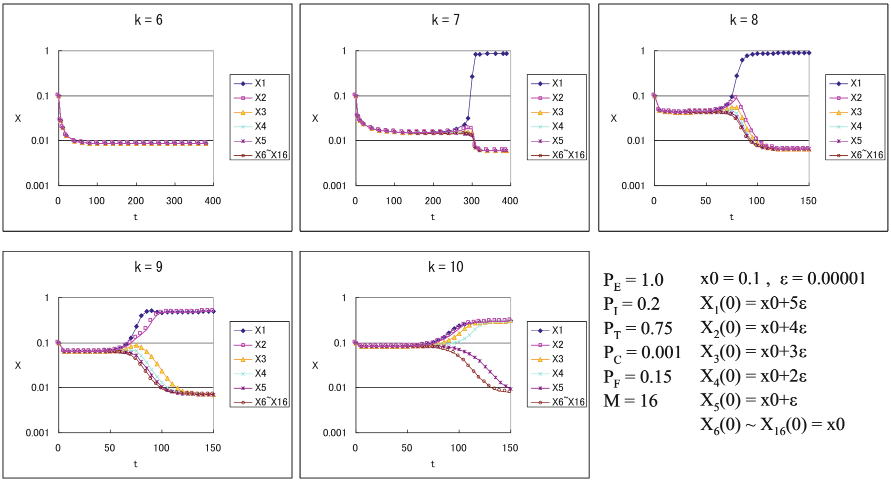

Fig. 10.3 Numerical example of bifurcation of the mean-field dynamics (10.2) ($M = 16$, $k = 6 \sim 10$) (Kunigami et al. 2010b). No emergence ($k \leq 6$), single emergence ($7 \leq k \leq 8$), and multiple emergence ($9 \leq k$) are observed

The second finding "the bifurcation phenomenon depends upon a characteristic of the social (interagent) network" comprises the following interesting outcomes. When the social network is "regular," Kunigami et al. (2010a, b) indicated analytically that the bifurcation depends upon the degree of the social network as follows:

- Non-emergence (no commodity has general acceptability), if the average network degree is small enough
- Single emergence (only one commodity emerges as proto-money), if the average degree grows larger than the lower critical value
- Multiple emergence (two or more commodities emerge as proto-money), if the average degree grows larger than the higher critical value (Fig. 10.3).

Further, they also numerically showed a "hub-effect" in that even a small number of hub-agents (nodes that have many more edges than the others) exist in the social network, bifurcation occurs more easily than in a social network without hub-agents.

In addition, a DSN simulation (Kobayashi et al. 2009a) study without mean-field approximation produced several outcomes as follows:

- First, in the case of a regular social network, the bifurcation of the emergence and its dependence upon the average degree of the social networks are both confirmed.
- Second, the hub-effect is also confirmed in that the existence of hub-agents enhances the emergence of proto-money.

- Third, in both a small-world network (Watts and Strogatz 1998) and a scale-free network (Barabasi and Albert 1999), the single emergence of proto-money is observed with lower average degree of the interagent network than in case of a regular network.

Kobayashi et al. (2009b) also applied DNS simulation to the emergence of a major mileage point from various mileage systems.

10.2.3 Collaborative Learning in Classroom and Teaching Strategies: An Educational Application of the Doubly Structural Network (DSN) Model

In the area of educational study, Kurahashi et al. (2014) and Kuniyoshi and Kurahashi (2017) proposed successful applications of the DSN model. They developed a novel type of simulation to investigate how knowledge is collaboratively disseminated to students in a classroom under various types of teaching strategies.

It is important to assess the collective process in which students comprehend certain knowledge. In the classroom, students obtain knowledge not only from a teacher but from other students as well. Effective classroom teaching consists of both how to impart the structural knowledge and how to enhance students' spontaneous collaboration. To evaluate effective teaching, the model needs to represent the structural knowledge transfer from the teacher to each student and knowledge dissemination through inter-student relationships in the classroom.

According to Kurahashi et al. (2014) and Kuniyoshi and Kurahashi (2017), the DSN model is applied to represent the collective learning process of students and to evaluate teaching strategies in the classroom, as follows:

- The class consists of two types of agent: a teacher and students.
- The knowledge consists of a certain number of learning materials that have structural propagation of understanding. This structure of propagation is estimated from learning data derived by a Bayesian network and represented as conditional probabilities.
- In the classroom, the teacher instructs the learning materials according to a certain teaching strategy, which includes the order of the instructing materials, the response to the students' understanding, and relationships among the students.
- Each student has a knowledge network of which nodes are the learning materials and edges are conditional understanding probabilities between two nodes. Each node has the binary status of the student's understanding. The knowledge network is regarded as an internal network of the student.
- Each student understands each instructed material according to (1) his/her academic ability based on the item response theory, (2) structural propagation of probabilities of knowledge understanding, and (3) collaboration with the other students.

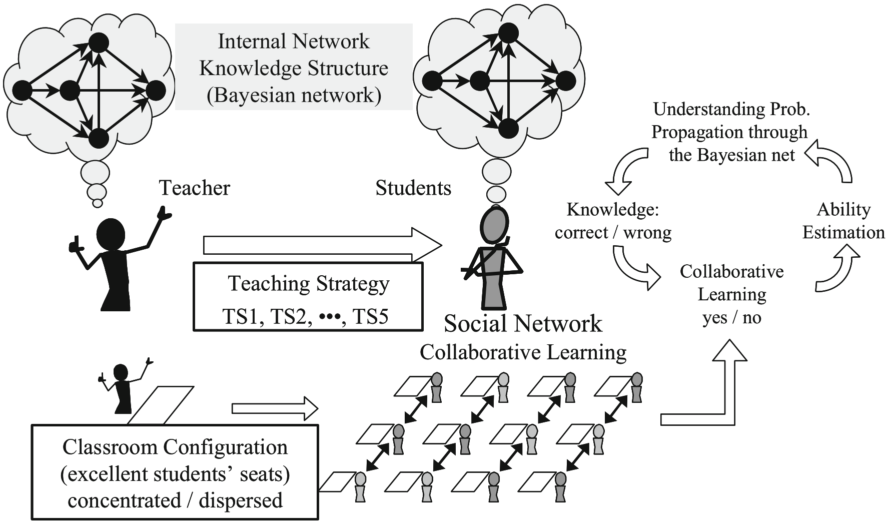

Fig. 10.4 Outline of the DSN classroom teaching simulation. (Drawn by the author based on Kurahashi et al. (2014))

- In the classroom, two adjoining students collaborate each other. These collaborative relationships are regarded as a social network, which is affected by the student allocation in the classroom.
- In each teaching session, the teacher selects and instructs one of the learning materials, and then all the students' understanding states are updated.
- A measure of effectiveness called "teaching time" is the number of teaching sessions required to let all students understand all learning materials. Another measure of effectiveness called "attainment degree" is the ratio of the understood learning materials among all students at the end of a certain teaching session (Fig. 10.4).

Using this simulation model, Kurahashi et al. (2014) and Kuniyoshi and Kurahashi 2017investigated the effectiveness of the following teaching strategies and the students' collaboration. In the collaboration, students helped the other student seated next to them:

- TS1: Teaching along with the complex doubly structured network method
- TS2: Teaching by selecting items to teach in a random manner
- TS3: Teaching an item where many learners gave wrong answers
- TS4: Teaching by considering the addition of average correct answers per model question to TS3
- TS5: Teaching by moving to the next item when all learners understood an item by order of the highest correct answer rate according to each model question

They evaluated and compared the teaching time and the attainment degree of these strategies under the collaborative and non-collaborative learning conditions. Ten runs of simulation (in a 30-student classroom) were conducted for each teaching strategy and the collaborative conditions.

Their results showed that the teaching strategy and existence of students' collaboration improved the effectiveness of teaching. For instance, TS1 achieved the shortest average teaching time and highest average attainment degree. TS2 was the second shortest and the second highest and TS3 the third and TS4 the fourth. Under the collaborative learning condition, each teaching strategy achieved shorter teaching times than the results under the non-collaborative condition.

They also investigated influence of classroom configurations (inter-students network structure) to the students' collaboration. For the configurations, capable (showing high academic capability in the TS simulation) students' seats were rearranged from the simulation of the TS as follows. Each simulation is conducted under TS1:

- The concentrated arrangement: The capable students are gathered at one side of the classroom, and the non-capable students are gathered at another side.
- The dispersed arrangement: Each capable student is seated next to a non-capable one.

Their results showed that the classroom configuration affects the learning effectiveness through the students' collaboration. For instance, the dispersed arrangement achieved a shorter average teaching time than both the concentrated arrangement and the simulation of the TS. In contrast, the concentrated arrangement required the longest average teaching time.

In addition, Kuniyoshi and Kurahashi (2017) conducted further study on group arrangement and found that the group arrangement was more effective than the students' collaboration learning in their previous work.

10.3 Educational Experimentations: Pictogram and Persona

Here, we are going to overview the experimental studies on how to actual persons' recognitions are represented or measured in various educational situations. In this area of study, we have proposed two new approaches. The first is the Pictogram Network (Pict-Net) Abstraction, whose representation is similar to the DSN formulation. Another one is the Persona Design Method, which is based on the two different kinds of the techniques applied in marketing research.

10.3.1 Pictogram Network (Pict-Net) Abstraction: An Experimental Educational Application

The Pictogram Network (Pict-Net) Abstraction was introduced by Yoshizawa et al. (2012, 2013) as a representation of human recognition using visual motives to improve peer reviewing for essay writing. The Pict-Net is semantic network whose nodes are pictograms. Each pictogram node represents word/object/concept, and each edge indicates the existence of a direct relationship between the adjoining objects/concepts. The Pict-Net abstraction represents the draft of an argument or an essay by making a Pict-Net.

The key concept of this approach is to use a semantic network to represent a drift of an argument or an essay. Making a semantic network of understandings was presented as an effective methodology to discriminate between an expert and a novice by Chi et al. (1981). Their result showed that in the network structures of the problem, elements reflected the depth of understanding between the PhD students (experts) and the undergraduates (novices).

The other key concept is to use visual motifs of recognition as well as linguistic information. The dual-coding theory (Paivio 1986) insists that our recognition consists of the verbal system, nonverbal system, and the interaction between them. The verbal system has a network structure of "logogens," and the nonverbal system has a network structure of "imagens." From a nonverbal aspect, Pict-Net abstraction highlights what do the human agents emphasize semantically.

The methodology of the Pict-Net abstraction was presented by Yoshizawa et al. (2012, 2013) and Yoshizawa (2015) to improve peer review for essay writing in EFL (English as a foreign language) composition class. They used Pict-Net abstraction to visualize both the writer's intention and the reviewer's understanding. The visualization enables the writer to realize that the reviewer's understanding was different from the writer's intention. The revision of essays was evaluated by the decrease of the network distance between the writer's and the reviewer's Pict-Nets (Fig. 10.5).

Yoshizawa et al. (2013) conducted the experiment as follows ($N = 8$):

- The instructor shows an essay theme and a list of pictograms related to the theme.
- Each writer creates their own pictogram networks (Pict-Nets) on the theme and then writes an essay.
- The writers exchange their Pict-Nets and create Pict-Nets based on the essay as a reviewer.
- The writers compare their own Pict-Nets with the reviewers' Pict-Nets (1st distance) and revise their essays.
- One new reviewer reads each revised essay and a created a Pict-Net based on the essay and compare the Pict-Nets (2nd distance).

As a result, seven of the eight revised essays showed a decrease in the Pict-Net distances, and four of them achieved more than a 10% decrease. This demonstrates that the Pict-Net abstraction is applicable to the peer review process.

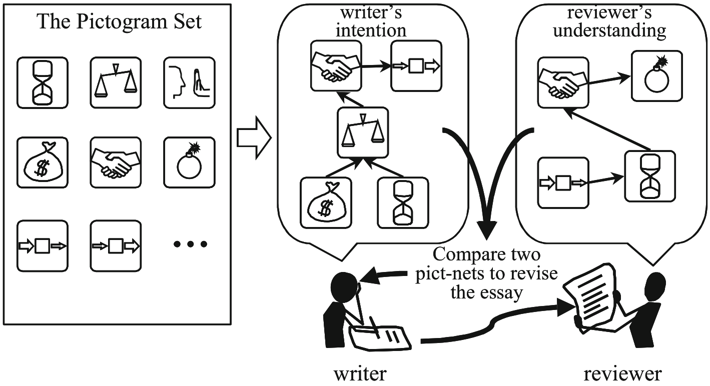

Fig. 10.5 Pictogram Network (Pict-Net) Abstraction for peer review. The difference between the writer's intention and the reviewer's understanding is visualized for feedback to the writer. (Drawn by the author based on Yoshizawa et al. (2012, 2013))

10.3.2 Persona Design of Business Leader Competences

Next, the Persona Design Method (Sasaki et al. 2014a, b; Terano et al. 2015) has been introduced to identify leader competencies that were recognized as "important" or "required" by various stakeholders. In business leader education, related stakeholders do not always have the same recognition and priorities of the competence requirements. This method enables us to detect the required competencies and to compare quantitatively the importance of the competencies.

According to Sasaki et al. (2014a) and Terano et al. (2015), the Persona Design Method consists of two different marketing techniques, the Persona method and the conjoint method. The Persona has been used as single archetypal user representing unknown target customers in user-centric marketing or in developing software (Cooper 1999). In Persona Design Method, Persona is a set of characteristics or attributes to embody a certain image of a target person. Conjoint analysis is also used for extracting the important characteristics or attributes of Persona. Conjoint analysis using the orthogonal design of experiments is a popular marketing technique to quantitatively find the customers' potential preferences (Fig. 10.6).

They conducted an experimental study of the Persona Design Method to detect the required competencies for business leaders as follows:

- Extract possible competencies of leaders from interviews.
- Create a set of Personas, and allocate these competences in each Persona by using an appropriate orthogonal array.
- Let subjects/respondents evaluate all the Personas.
- Analyze the subjects' data via a multivariate linear model to find out the important competencies from the subjects' view (Fig. 10.7).

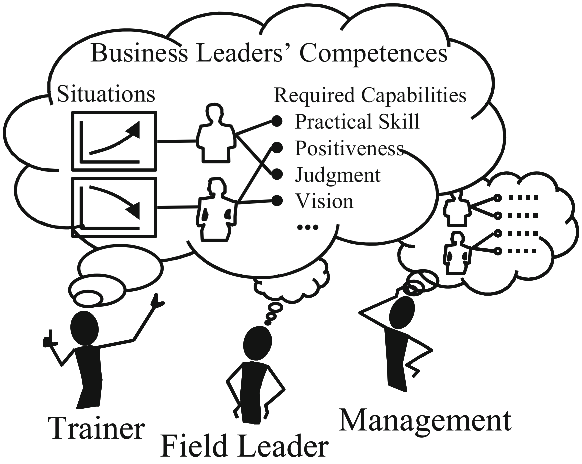

Fig. 10.6 Related stakeholders do not always have same priorities concerning competency requirements for their business leader education

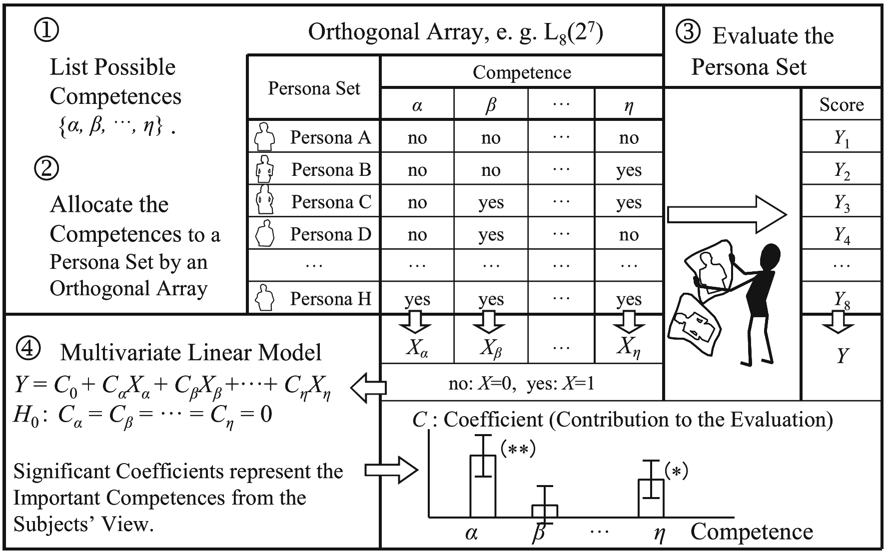

Fig. 10.7 Procedure of the Persona Design Method for detecting business leader competencies

In the experiment (Sasaki et al. 2014a; Terano et al. 2015), they compared subjects' recognition of the competencies, under various assumed business situations. (The orthogonal array: $L_8(2^7)$, $N = 25$) (Fig. 10.8).

They demonstrated that the Persona Design Method statistically identifies the subjects' recognition of the important competencies needed for business leaders. Their results indicated showed that these competences had significantly different importance in the subjects' recognition and the importance was affected by the business situation. They also showed the influence of the subjects' experience (years in service).

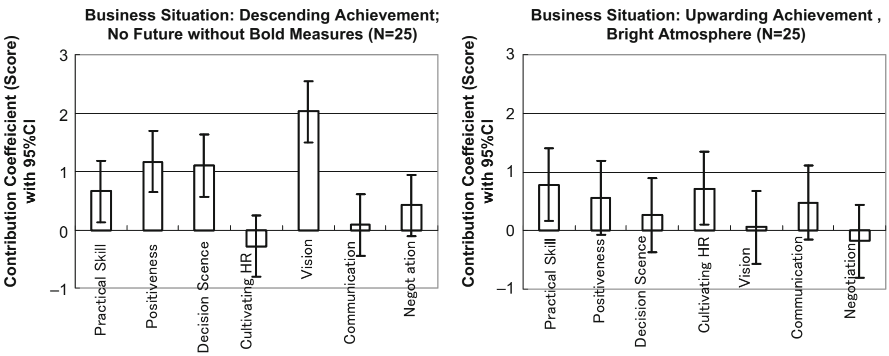

Fig. 10.8 Part of the experiment results (Sasaki et al. 2014a). The subjects' recognition of the leaders' competence is affected by the assumed business situations

10.4 Summary

In summary, we have overviewed recent progress on agent's cognition modeling, simulation, and experimental observation. On the modeling and simulation, we introduced a new formulation called the Doubly Structural Network (DSN) model and showed its applications in socioeconomics and education. For the experimental observation, we overviewed two educational applications called the Pictogram Network (Pict-Net) Abstraction and the Persona Design Method.

In Sect. 10.2, we introduced the DSN model formulation, the dynamical analysis and simulation on the emergence of money, and simulation on the classroom education. On the emergence of money, both the analytical approach and simulation approach showed that the single or plural emergence of money were dependent on the characteristics of an agent's social network. On the classroom education, the DNS teaching simulation demonstrated that it enables us to evaluate teaching strategies and seating allocation for the encouragement of students' collaborative learning.

In Sect. 10.3, we overviewed two experimental approaches in educational application. The first is the Pictogram Network (Pict-Net) Abstraction. This approach has similar formulation to the DNS model, uses visual images, and is used for visualizing a personal semantic network. Applying to essay writing with peer review, the experiment showed the Pict-Net abstraction was effective in reducing the distance of the Pict-Nets between the writer's intention and reviewer's understanding. The second approach is the Persona Design Method. This method uses a set of Persona generated by an orthogonal array and detects agents' potential attitudes that emphasize particular characteristics in the Personas. In application to extract the competencies of business leaders, the experiments demonstrated that the Persona Design Method is able to extract the important competences in stakeholders' recognition and these competences depended on both business situations and the stakeholders' backgrounds.

Acknowledgments Here, I express my sincere appreciation for the authors of which work and results I illustrate in this paper.

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Chapter 11
Model Prediction and Inverse Simulation

Setsuya Kurahashi

Abstract A societal system study investigates a targeted social case in order to extract universal structures behind the scenes while modelling the extracted structures. By demonstrating that the investigated social case is explicable, this study verifies the validity of the theory. This paper introduces inference methods for agent model parameters and inverse simulation methods for verifying validity within a societal system study. This paper then attempts to describe that these methods correspond to the optimal control problem in a dynamic model. The latter part of this paper introduces the Chinese imperial examination model as the case of inductive inference based on an inverse simulation method and the labour market model as a case of deductive inference.

11.1 Introduction

Agent-based modelling (ABM) is dependent on the agent technology to act based on autonomous decision-making. Agent-based simulation (ABS) has developed by expanding to multiple agents in order to apply ABM to a societal or ecological system. Being different from the engineering multi-agent system which is oriented to solve problems through interactions among multiple agents, the social-scientific multi-agent system which is oriented to conduct analysis aims to clarify complex social system phenomena. This is also referred to as generative social science, which aims that different and autonomous agents explain the generation of macroscopic social order in a generative fashion through locally dispersed interactions (Epstein 2007).

On the other hand, one criticism of ABS is that it is unclear to what extent ABS can reflect the reality and whether models are designed on impulse or not. Of course, many objections have been made in this regard. However, we must always

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give serious attention to the question as to how accurate the actual world can be modelled. Focusing on this point, this paper looks back at the history of science in order to introduce one method so that ABS can develop to more reliable social science. Chapter 2 overviews the validity of modelling and the scientific method. Chapter 3 explains ABM as an inductive inference, while Chap. 4 explains ABM as deductive inference. Chapter 5 explains pattern orientation, and finally Chap. 6 serves as a summary of all.

11.2 Validity of Modelling and Scientific Methods

The previous chapter described that social simulation is generative social science. This is also referred to as the constructive approach. This approach models the actual world on a computer in order to observe possible social phenomena repeatedly by generating several scenarios given diverse parameter settings. Modelling a society requires the building of a structure based on observational data and setting parameters. On the other hand, generating social phenomena while assuming several scenarios requires the design of logically correct hypotheses and functions by adopting the theorems and the definitions based on a certain axiomatic system. In such a sense, social simulation as generative social science has natures of both the inductive method and the deductive method. This fact not only serves as the attractiveness of this science but also causes some difficulties and places for criticism. Prior to reaching the core of this issue, this chapter describes the scientific method as common knowledge.

The scientific method (Gauch 2003) is believed to date from the Islamic society in the eleventh century. The writing authored by an astronomer who was born in Basra (in present Iraq), Ibn al-Haytham (Alhazen), indicated the importance of hypothesis verification as a scientific method (Smith 2001). In the nineteenth century, a British scientist, Whewell, elaborately theorised the scientific method. The basic thoughts are as follows (Whewell 1840):

1. Observe a specific natural phenomenon or a specific phenomenon in the actual society.
2. If there are no existing theories or solutions that can explain the observed phenomenon, generate and formulate questions for considering why the observed phenomenon could occur and how that phenomenon can be dealt with.
3. Create a hypothesis that can adequately explain the questions. The hypothesis created here has to be an inference, a prediction or a statistical hypothesis which should be falsifiable.
4. Design, build and implement inferences and experiments in order to verify the hypothesis.
5. Analyse whether the inference and experimental results match with the observed phenomenon. If the results do not match or match inadequately, repeat the loop of recreating the hypothesis, implementing inferences and experiments and verifying the results, so as to conduct a deeper analysis and consideration.

Let us look at a specific case to consider this method. One of the epoch-making events in the history of science in the twentieth century is discovery of the double-helical structure of DNA. Adopting this scientific method from the initial stage, Watson and Crick observed that DNA is comprised in such a way in order to carry basic genetic information. This was the first step of the observational phase. In the second step, the question phase, they created the question as to why DNA can store genetic information. In the third step, the hypothesis phase, by using the mathematical method of graphics transformation, they created a hypothesis and prediction that DNA should be X-shaped in X-ray imaging because of its helical structure. In the fourth step, the verification phase, they implemented experiments to capture X-ray images. These images of X-shaped DNA were called "photo51." In the fifth step, the analysis phase, they verified the fact that this diffraction pattern was in a helical shape. Based on this verification, they modelled hydrogen bonding of DNA. They received the Nobel Prize in Physiology for this discovery.

If the purpose of the scientific approach is to abstract and simplify a complicated phenomenon by modelling in order to discover the principles and laws behind the phenomenon, the scientific method described above is, therefore, about how to discover and formulate the model created, and to verify the validity. On the other hand, here, inferences used here are broadly divided into the following two methods: inductive inference and deductive inference. Inverse simulation has the characteristics of both inference methods, while having the function of generative inference that can show how it may be possible to reach the solution. The next chapter including the subsequent pages will describe the association between inverse simulation and these inference methods.

11.3 Inverse Simulation Method

While consisting of simple architectures, diverse generative phenomena that demonstrate organisational behaviour more than the functions incorporated within the model are shown by simulations based on ABM. In general, such simulations are executed based on the forward direction procedure (forward simulation) as shown below.

1. Design the model based on a small number of parameters.
2. Set parameters.
3. Execute the simulation.
4. Evaluate the results, adjust the parameters and then return to 2.

However, these simulations produced the following three major issues.

Issue1 Where the functions that are implemented by each agent are too simple, it causes difficulty in using them for analysis of the complicated real world.

Issue 2 On the other hand, when the model's parameters are increased, the answer is highly likely to be hidden within the model itself.

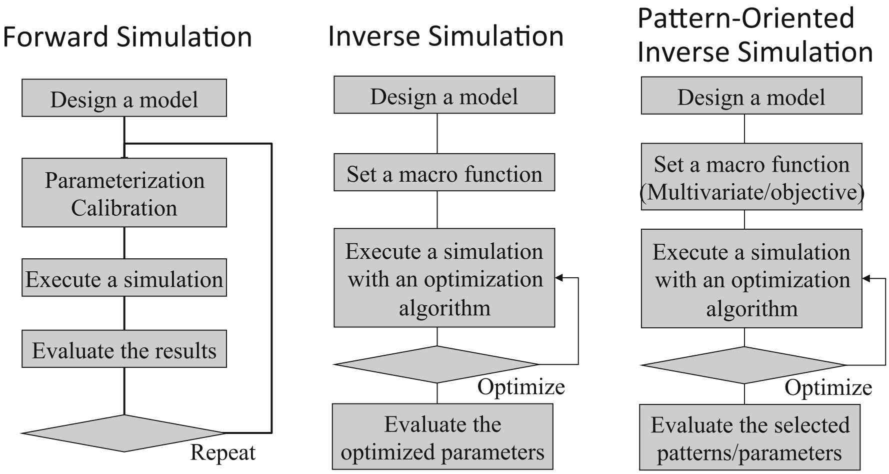

Fig. 11.1 Forward simulation (Left), inverse simulation (Middle), pattern-oriented simulation (Right)

Issue 3 The relevance between the results of executing the model and the generative phenomena of the real world is unclear.

As for issue 1, designing agents having abundant functions and parameters can clarify the computational meaning of social science. As for issue 2, we need to avoid adjusting the model's parameters arbitrarily, while developing a proper method to do so. As for issue 3, we need to investigate the association between macroscopic information which can be observed in actual social phenomena and data obtained by simulation.

As described above, the previous studies have had the issue that simulation could achieve the results as expected because the designer would set the parameters. Given this issue, the inverse simulation method was proposed in order to solve large-scale inverse problems (Kurahashi et al. 1999; Kurahashi and Terano 2001). Adjusting parameters can possibly create a predetermined result. While on the other hand, inverse simulation is executed based on the following procedure (Fig. 11.1):

1. Design the model based on a large number of parameters that express the real world.
2. Set the evaluation functions that are actually used.
3. Execute simulation by using the evaluation functions as objective functions.
4. Evaluate the initial parameters obtained.

However, it is generally difficult to adjust such a large number of parameters for the objective functions. Given this fact, inverse simulation adopts the evolutionary computing method, which can optimise functions with complicated and a large number of variables, and the reinforcement learning method. Simulation is basically executed as follows:

1. Multiple societies are generated from the social gene pool.
2. A number of agents exist within each society, which are initialised into diverse characteristics based on a number of parameters described in genes of the societies to which the agents belong.
3. Agents develop their own activities for a certain period according to the model's descriptions, while being measured based on the evaluation function that is used in the actual society.
4. Based on the measurement results, the social genes are processed with a series of genetic algorithms, such as adaptive assessment, selection, crossover and mutation. They result in updating the social gene pool one after another.

Inverse simulation is a means for exploring the following solution space. Suppose that a set of the results of social simulation measured based on the actual social index is U, while a set of characters of a group of agents is X. Here, the mapping f that correspond the point u of U to the point $\mathbf{x}$ of X indicates the relationship of $f : \mathbf{x} \rightarrow u$ that determines the social index according to the attribute value which indicates the agent's character. Where there exists the relationship of $f^{-1} : u \rightarrow \mathbf{x}$ the attribute $\mathbf{x}$ can be obtained from u. The evolutionary algorithm used here has the basic structure that generates a number of factors, $\mathbf{x}$, of X in order to obtain $\mathbf{x}$ that is related to the point u. Since the factors are evaluated from a number of random initial values, there is no need to presume the convexity of the solution space. This shows that the character of each agent to be obtained is at least one solution that characterises the macroscopic social index. The following chapter describes that the inverse simulation method can be applied to both inductive and deductive inferences.

11.4 Inverse Simulation as an Inductive Inference

This chapter introduces the method, including the case example, for using the inverse simulation method for inductive inferences to approximate the model to the real society. An inductive inference is a method that collects many samples of phenomena and estimates the association between the common characteristics in the samples and the phenomena in order to derive the general principles. Therefore, the conclusion derived is not necessarily inevitable, but probable.

One of the major inductive inference methods is the statistical method. In the seventeenth century, scientists including William Petty of England began pioneer effects towards statistics such as population phenomena. In the nineteenth century, their efforts achieved development based on the Gaussian Law or Error as to the introduction of the theories about regression and statistical testing by Pearson and Fisher. The foundation of statistics underlies law of error. Every measurement has errors. Where the true value is X, the measured value is obtained by $X + e$. Here, e indicates an error. When the model approximates towards the true value, X, ideally, the law of error in this ideal case is the Gaussian law of error, where the average error is 0 and the error variance is σ^2. When the maximum principle is considered based on the law of error, the true value, X, as a regression model is believed to be estimated by the method of least squares.

The inverse simulation method as an inductive inference is what applies this concept to ABM. Where the measured value is expressed as $x_1, x_2, \ldots, x_n$, each error obtained by $e_i = x_i - X$ should occur at the highest probability based on the true value, X. The true model is estimated by minimising the sum of squares of the error, namely $\min_i \sum (x_i - X)^2$. Specifically, any similarity function is defined for the value obtained by observing the actual society by the symbol X. The state variables are calibrated to minimise the sum of squares of the error from the achieved value obtained by the defined similarity function and simulation, in order to optimise the model parameters. Here, we must notice that there is not always one optimum value. The following section introduces one case where this method was applied.

11.5 Chinese Imperial Examination Model

This case is about agent-based analysis on about 500 years of the history of one family line which produced many applicants who successfully passed the Chinese imperial examinations based on the record of family lines during the Ming and Qing periods in China (Kurahashi and Terano 2008; Yang et al. 2009). In this case, the family line networks and individual profile data were expressed respectively as the adjacency matrix and the attribute matrix, and the profile data of the family of the successful applicants was defined as the objective function. With these things, an inverse simulation was implemented by a multi-agent model. Bourdieu (1979) proposed the structure of reproduction related to cultural capital and education. In his study he indicated that the normative system in family would reproduce cultural capital while playing a critical role in selecting the social scale. He also indicated the role played by cultural capital in examinations as the selection mechanism in various cases such as the examinations conducted in the French educational system and the Chinese imperial examinations, which served as the bureaucrat selection system, in the traditional Chinese society. In our modern society, however, globalisation has advanced, and at the same time, social systems and regional communities have changed. This situation has forced traditional forms of families to change in each region. Amid such circumstances, it has become increasingly important to learn the functions of a family which serves as a basic element of the social system.

On the other hand, sociological approaches in the field of family studies have also faced significant changes. There have been various sociological approaches, such as the traditional comparative institutional approach, the historically sociological approach and the communicative approach. In addition, the historical demography approach that captures time-series changes in family structures and population sizes, and the network theory approach that incorporates methods for analysing social networks have also appeared. As described above, the field of family studies has gradually changed into sociology which is computable.

The study case described in this section attempted to analyse the family system in one family line in China that lasted for about 500 years by building an ABM based on the knowledge of historical sociology, historical demography, the cultural capital theory, the social capital theory and social networks. By simulating time-series changes related to the attributes of family members, this study also clarified the normative system possessed by a family by using the inverse simulation method. This study was novel because of creating a computable model of complicated social phenomena, such as dynamics in history, based on scientific positive analysis conducted by means of a philological method, by using social network analysis and multi-agent technology. These attempts demonstrated the effectiveness of ABM by using the inverse simulation method in historical studies.

This study, by simulating time-series changes related to the attributes of family members, clarified the normative system possessed by a family by using the inverse simulation method. The record of family lines used in this study was created in the Ming and Qing periods, while the lineage, which indicates the family tree, and the family table, which records the details about each family member's profile, were used as observational data. The following shows the model outline, while Fig. 11.2 shows a part of the family table.

- Each agent, in line with the family tree expressed by the adjacency matrix, transmits cultural capital face to face, from the father, the mother, the grandfather and the great-grandfather to their descendants.
- Agents can have two kinds of cultural capital, knowledge cultural capital and artistic cultural capital.
- Children have individual characteristics, the native knowledge characteristic and the artistic characteristic. These characteristic values are randomly given to each child.
- The cultural capital degree for a child is determined based on the following factors: the child's characteristics and cultural capital transmitted by others. However, only knowledge cultural capital affects the success in the Chinese imperial examinations, while artistic cultural capital does not have any influence on the child's pass rate of the examinations.

Each agent can take the above-mentioned actions. At the same time, each agent has the parameters that determine each agent's behavioural patterns. The following shows the parameters that are common among all agents. The parameters include the intrafamilial transmission function (the father, the grandfather and the great-grandfather), the influence degree of cultural capital towards individuals (the transmission ratio from the father and other individuals), the educational influence degree (the increase ratio due to cultural capital and education for characteristics), the cultural capital transmission function (how knowledge cultural capital and artistic cultural capital are transmitted) and the influence degree from the mother's family (the cultural capital transmission ratio).

The intrafamilial transmission function is provided in the following formats (Fig.11.3). The cultural capital of somatization used in this model is mainly transmitted through domestic circumstances. These five functions express the

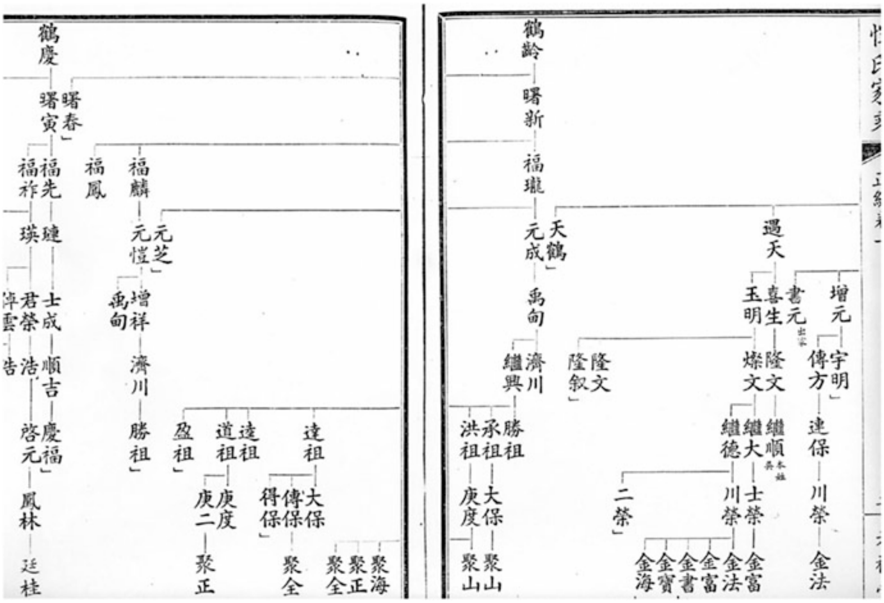

Fig. 11.2 The family table

$$\text{Mode1}: cl_i^c = transmit_j(cl_i^p)$$

$$\text{Mode2}: cl_i^c = transmit_j(cl_i^p) + transmit_j(cl_i^{gp})$$

$$\text{Mode3}: cl_i^c = transmit_j(cl_i^p) + transmit_j(cl_i^{gp}) + transmit_j(cl_i^{ggp})$$

$$\text{Mode4}: cl_i^c = transmit_j(cl_i^{gp})$$

$$\text{Mode5}: cl_i^c = m_1 \cdot transmit_j(cl_i^p) + m_2 \cdot transmit_j(cl_i^{gp}) + m_3 \cdot transmit_j(cl_i^{ggp})$$

cl_i^p : cultural capital of father

cl_i^{gp} : cultural capital of grandfather

cl_i^{ggp} : cultural capital of great - grandfather

m_i : transimission rate between generations

Fig. 11.3 Intrafamilial transmission function

transmission from each, the great-grandfather, the grandfather and the father, who are considered to living together as a family.

Additionally, the cultural capital transmission function is provided by the following formats (Fig. 11.4).

As clarified by Bourdieu, cultural capital is indicated by academic capital measured mainly as knowledge, while school education including music and painting is indicated as an aesthetic orientation in light green. While these things

$$
\begin{aligned}
\text{tramsmit}_1: & \ cl_k^c = r(cl_k^p \cdot ps_k^c) \\
& \ cl_a^c = (1-r)(cl_k^p \cdot ps_a^c) \\
\text{tramsmit}_2: & \ cl_k^c = (cl_k^p + ps_k^c)/2 \\
& \ cl_a^c = cl_a^p/2 \\
\text{tramsmit}_3: & \ cl_k^c = r(cl_k^p \cdot p_k^c) + (1-r)(cl_a^p \cdot ps_k^c) \\
& \ cl_a^c = (1-r)(cl_k^p \cdot p_a^c) + r(cl_a^p \cdot ps_a^c) \\
\text{tramsmit}_4: & \ cl_k^c = r(cl_k^p + p_k^c)/2 + (1-r)(cl_a^p + ps_a^c)/2 \\
& \ cl_a^c = r(cl_a^p + p_a^c)/2 + (1-r)(cl_k^p + ps_k^c)/2 \\
\text{tramsmit}_5: & \ cl_k^c = r(cl_k^p \cdot p_k^c) + (1-r)(cl_a^p \cdot ps_a^c), \\
& \ cl_a^c = r(cl_a^p \cdot p_a^c) + (1-r)(cl_k^p \cdot ps_k^c) \\
\text{tramsmit}_6: & \ cl_k^c = (cl_k^p + ps_k^c)/2 \\
& \ cl_a^c = (cl_a^p + ps_a^c)/2 \\
\text{tramsmit}_7: & \ cl_k^c = cl_k^p \cdot ps_k^c \\
& \ cl_a^c = cl_a^p \cdot ps_a^c \\
\text{tramsmit}_8: & \ cl_k^c = m(r(cl_k^p \cdot p_k^c) + (1-r)(cl_a^p \cdot ps_a^c)) \\
& \ cl_a^c = m(r(cl_a^p \cdot p_a^c) + (1-r)(cl_k^p \cdot ps_k^c))
\end{aligned}
$$

cl_k^c : knowledge cultural capital of a child
cl_a^c : art cultural capital of a child
cl_k^p : knowledge cultural capital of a parent
cl_a^p : art cultural capital of a parent
ps_k^c : knowledge character of a child
ps_a^c : art character of a child
r : cultural capital crossover rate
m : cultural capital transmission rate

Fig. 11.4 Cultural capital transmission function

were defined as knowledge capital and artistic capital, the transmission of cultural capital was modelled by using the transmission function with intersections of these two kinds of capital. However, the form of this transmission function was unknown. Therefore, with multiple different functions additionally defined, function selection and variable estimation were conducted by inverse simulation so that the squared error from the actual number of the successful applicants of Chinese imperial examinations would be minimised.

This model, as shown in Fig. 11.4, defined eight functions based on various mathematical elements including products, sums, averages, and correlation coefficients. Unlike typical forward simulation methods, the inverse simulation method does not explicitly give the behavioural rules that agents or environments possess, and other parameters. Instead, the inverse simulation method gives the macroscopic social index, which is to be explained by the model (e.g. the degree of inequality, centrality, sharing, etc.), as objective functions, in order to explore the agent's behavioural parameters by using the optimisation method as the form of inverse problem analysis. Figure 11.5 shows the model.

As shown in this figure, each kind of cultural capital, which is transmitted along the family tree, is transmitted to children by means of the normative system and the parameters that characterise this system. Multiple agent simulations are simultaneously implemented based on these rules. The profile information of all the agents, which is output as the results of simulations, is compared with the actual profile information based on attribution data created from the family table. This

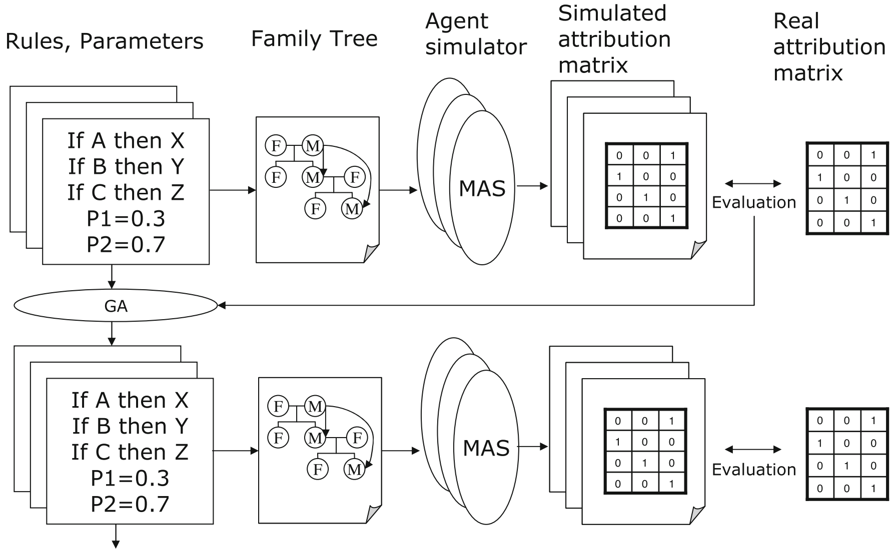

Fig. 11.5 The inverse simulation model of family tree

profile data should be aggregated according to each cohort. The objective function should be the error of mean square between the simulator profile information and the actual data profile information. This objective function is expressed as shown below.

$$min : CohortFitness = \sum_{i=1}^{n} \sum_{j=1}^{m} (c_{ij} - sc_{ij})^2,$$

Here, c_{ij} indicates the cultural capital by cohort in the actual profile data, while sc_{ij} indicates the cultural capital by cohort within the simulation. To obtain the cultural capital of actual data, the following successful applicants of the Chinese imperial examinations, who are usually conducted to passing the examinations in historical reference materials, Jinshi (advanced scholar), Juren (recommended man) and Gongsheng (tribute student), possess 1 as knowledge capital or otherwise 0. Those described as painters or poets possess 1 as cultural capital, or otherwise 0.

The analysis based on the simple linear regression model for the actual data and the simulation results ($\hat{r} = a_1 * s + a_2$, here, $\hat{r}$ indicates the estimated number of the actual successful applicants, s indicates the number of the successful applicants through simulation, a_1 and a_2 indicate the regression coefficient and fragment) resulted in t: 6.04 and p: $1.41 * 10^{-6}$, confirming that there was a significant correlation. For comparison, estimation was conducted based on the next auto-regressive model (AR) as the statistical model and the next generalised linear model (GLM). As the result, the error of mean square with the actual data was 4.75 in the AR model and 1.92 in the GLM model, while 1.12 in the inverse simulation model.

With this result, this model demonstrated its effectiveness. Analysis of estimated parameters resulted in finding that the grandfather and the mother significantly affected the transmission of cultural capital to children in the family circle, while discovering the normative system maintained by the family.

11.6 Inverse Simulation as a Deductive Inference

As typified by a syllogism, a deductive inference is an inference method which starts from the general and correct principles or hypotheses in order to derive more specific individual statements based on a logical inference. Many mathematical models build their own theoretical systems based on this deductive inference. According to this logical structure, a correct premise can naturally derive the correct conclusion (if the premise is incorrect, the conclusion derived is also incorrect). What about ABM? Some have been critical of ABM concluding that it is not deductively different from mathematical models. However, ABM is a computer programme which can be processed on a Turing machine. Therefore, there exist equivalent inductive functions, where the initial values can be computable deterministically. Inductive functions can also be converted to the first-order predicate logic, while the result of ABM technically becomes a theorem.

On the other hand, the deductive method converts the implicit truth that is originally contained in the hypothesis or the premise into the explicit truth by means of inference. Hence, this method does not discover new facts that are not found in the hypothesis or the premise. From the constructive standpoint of ABM, however, we can affirm as follows: As found in Gödel's incompleteness theorems, in the study of mathematical logic, it is distinguished whether a proposition is true or provable. For instance, as is common with economic models, there have existed many problems that although a certain balance is proved, the balance cannot be reached or cannot be reached within real time (Epstein 2007). On the other hand, although ABM makes it possible to give proof deductively, it is a generative method that shows the structure as to what procedures, combinations or ways can lead us to the solution within real time. In this sense, ABM is a generative science which indicates reachability.

One of the macroeconomic models based on the deductive inference uses dynamic programming. This model is not static optimisation, but it obtains a control variable sequence that maximises the objective variable for problems such as a labour market with the concept of time or policy optimisation. In order to find such optimal policy functions, the problem is formulated into a problem that obtains the control variable sequence, u_s, which maximises the value function V under the state variable x, the initial value x_0, the constraint condition $x_{t+1} = g(x_t, u_t)$ and the utility function r (Ljungqvist and Sargent 2004).

$$V_{x_0} = max_{\{u_s\}_{s=0}^{\infty}} \sum_{t=0}^{\infty} \gamma^t r_{x_t,u_t} \tag{11.1}$$

This equation can be converted by using Bellman equation of optimisation, which is a well-known reinforcement learning problem (Sutton and Barto 1998).

$$V_{x_t,u_t} \leftarrow V_{x_t,u_t} + \alpha[r_{t+1} + \gamma \max V_{x_{t+1},u} - V_{x_t,u_t}] \tag{11.2}$$

This process serves to model the macroeconomic problem, which conducts optimisation over time by using dynamic programming, as an inverse simulation model.

11.6.1 Labour Market Model

This section introduces a case that modelled a labour market for new graduates by using a deductive inference in order to analyse effective support measures for job-hunting activities for students (Mori and Kurahashi 2011). Focusing on the labour market for new graduates, this study clarified the characteristics, the establishment process and the structure of this market. This study then examines methods for streamlining the hiring and recruitment activities for both the students and the companies in this market. Many Japanese enterprises adopt Japanese employment systems based mainly on a lifelong employment as their form of labour management, along with a seniority system, and an enterprise union. In order to have a supply of new and youthful of employees that are highly adaptable and stable, the periodic hiring and employment of new graduates have played an important role in such Japanese employment systems. Taking account of these characteristics, based on ABM, we modelled the activities developed by the students and the companies within the new graduate employment market, which had been difficult to solve analytically by using a mathematical model. In addition, we proposed an inverse simulation-based method for exploring efficient measures for increasing the rate of successful job seekers in the entire market, while streamlining job matching within the new graduate student employment market. Figure 11.6 shows the model outline.

The reinforcement learning method adopted for this model is the actor-critic method. As for efficient support measures which were found by optimising the control variable through time, the inverse simulation conducted discovered various findings. For example, during the middle of the job-hunting activities, it would be effective to give students at the middle or lower academic level careful employment guidance to select proper companies according to their own abilities. During the end period, support measures, which promote aggressive employment activities to reduce application intervals, given to the students at the lower academic level would be effective to enhance the rate of successful job seekers in the market (Fig. 11.7). Such effective support measures for job-hunting activities cover a broad range of areas, such as time and cost for selection by companies, and government employment support, in addition to the job-hunting activities developed by the students. Consideration including these areas has still remained as an issue to work on. However, this case modelled the dynamic structure of the new graduate employment market in Japan and demonstrated how to discover effective and

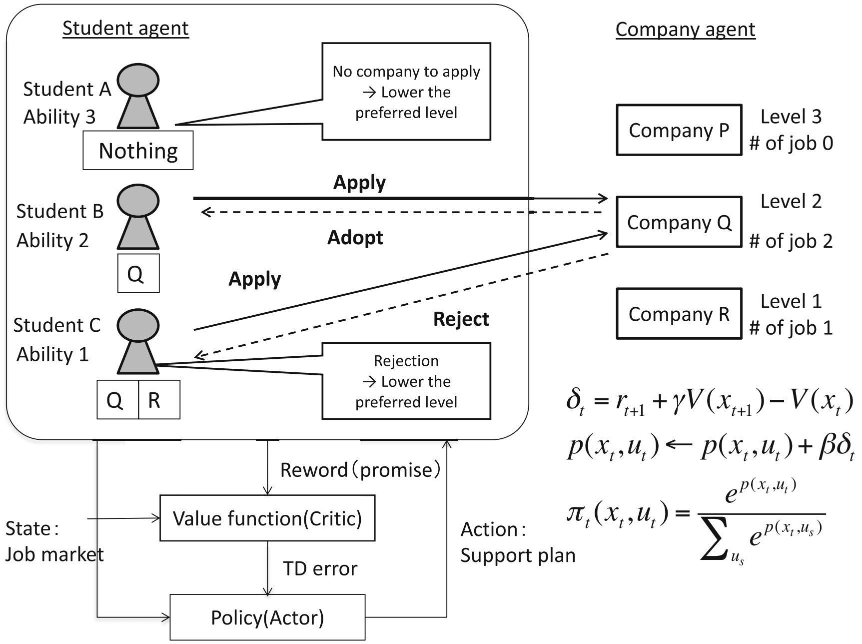

Fig. 11.6 The model of effective support measures for job-hunting activities for students

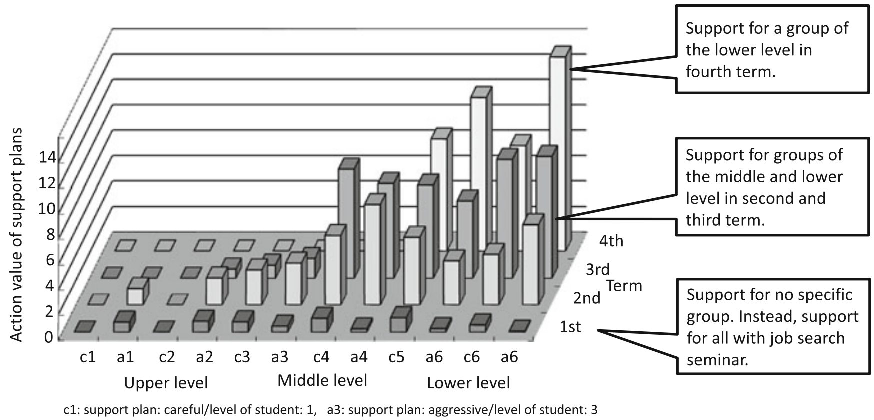

Fig. 11.7 Action values of support measures

reachable support measures for job-hunting students. This fact has shown the possibility that our study can contribute to enhancing social utility.

11.7 Pattern-Oriented Inverse Simulation

Many researchers have proposed the method referred to as strong inference during the development of scientific methods (Platt 1964). This inference method is characterised by creating not a single hypothesis, but multiple hypotheses. This method is implemented according to the following procedure:

1. Create multiple alternative hypotheses.
2. Plan an experiment to exclude some of the alternative hypotheses created.
3. Implement an experiment to obtain the clear results.
4. Generating sub-hypotheses and sequential hypotheses to refine the remaining possibilities, repeat these steps.

Needless to say, this procedure should be a natural method from the viewpoint of modern scientists and engineers. However, science which has incorporated this scientific method is believed to have achieved significant success from the nineteenth to the twentieth century. The pattern-oriented modelling (POM) method, which will be described in the next section, adopts this inference method (Grimm 2005; Railsback and Grimm 2010). POM considers a model to be a filter that copies the reality, while observational data that is extracted through the filter is referred to as a pattern. This pattern is easy-to-understanding qualitative information that is simpler than the actual phenomenon. The pattern is also referred to as a regularity, a signal and a stylised fact. Suppose that a certain individual is identified at an airport. In this case, inadequate information such as gender, age, clothing and bags (not adequate information such as the name and ID) is used for identification. This information serves as a pattern. However, it is usually difficult to determine what kind of filter (model) should be used to extract patterns in advance. For this reason, a multi-pattern method that observes multiple patterns is adopted for POM. Although weak patterns are extracted through each individual single filter, if they are qualitatively diverse, they can become stronger depending on the combination of patterns. The following shows the procedure for a pattern-oriented modelling based on a strong inference method:

1. Create multiple alternative hypotheses.
2. Implement ABM that tests these alternative hypotheses.
3. Implement an experiment in order to compare the alternative hypotheses whether they can generate characteristic patterns or not.
4. Review the behavioural characteristics, and search for further patterns which solve the differences between the alternative hypotheses. Repeat the tests until the characteristics that properly generate characteristic patterns are found.

Usually, the desirable number of alternative hypotheses is from about 2–4. The ODD (Overview, Design Concepts, and Details) protocols (Grimm et al. 2006; Grimmet et al. 2006) are recommended for use when implementing ABM. The model constitution entity and the state variable are then designed so that the patterns based on the alternative hypotheses created are generated.

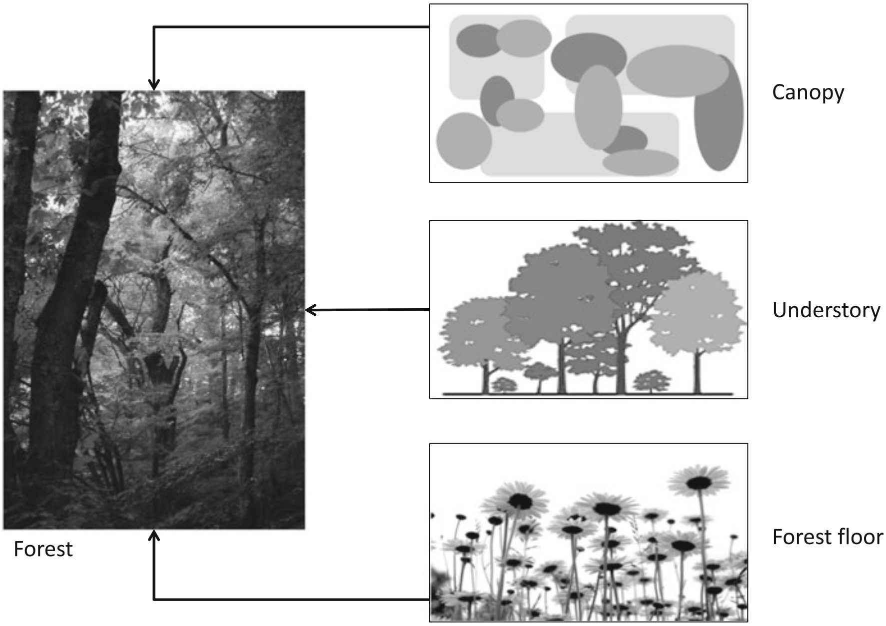

Fig. 11.8 The forest model with multiple patterns

The following section describes a simple case of POM in a forest (Fig. 11.8). Modelling of the forest ecology can extract the canopy patterns that indicate the distribution of vegetation observed from the above. At the same time, this modelling can also lead us to obtain the low patterns of trees observed in the forest, and the forest floor patterns where the vegetation on the ground of the forest was observed. When not any one of the patterns observed in the actual forest but each respective characteristic of multiple patterns (here, the canopy, the lower level and the forest floor) matches, we might say that the relevant model can accurately reproduce reality.

11.7.1 Chinese Imperial Examination Model Based on Pattern-Oriented Inverse Simulation

This section introduces the case that applied the pattern-oriented inverse simulation method for the Chinese imperial examination model which was described in Chap. 4 (Yang et al. 2012). The previous model simply synthesised multiple patterns to conduct inverse simulation. Therefore, it was impossible to understand superior combinations of patterns. Given that, we decided to create multiple hypotheses and use corresponding patterns for verification. The following four hypotheses

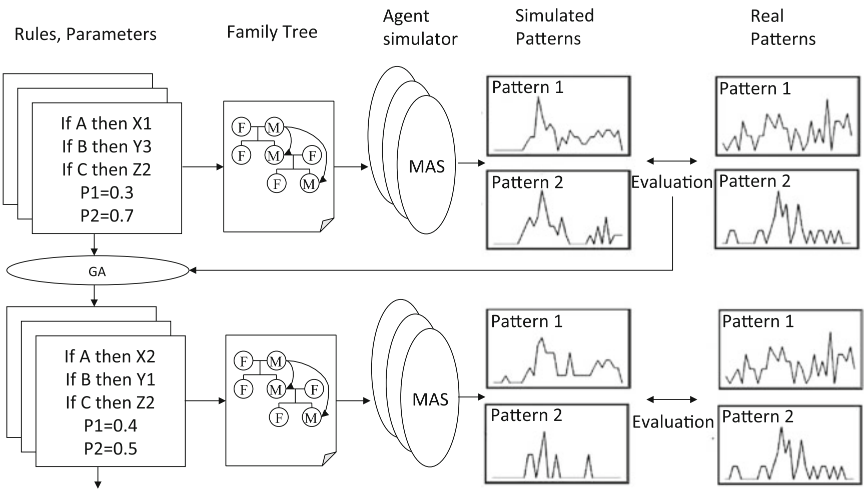

Fig. 11.9 Pattern-oriented inverse simulation model

were created: (1) all the successful applicants of the Chinese imperial examinations have influence on their descendants; (2) the highest successful applicants called Jinshi have influence on their descendants; (3) the applicants (students that aim to be Jinshi or successful applicants of lower examinations) have influence on their descendants; and (4) the painters have influence on their descendants. Extracting the four corresponding patterns to these hypotheses, the number of all the successful applicants, the number of successful Jinshi applicants, the number of applicants and the number of painters, from the family line data, we verified if this could be reproduced by using ABM. Figure 11.9 shows the conceptual diagram of the pattern-oriented inverse simulation model.

We used the real-coded genetic algorithm, UNDX (Ono et al. 1999), which showed excellent performance that optimised the multimodal function, for inverse simulation computation. We also implemented the following experiments with each hypothesis and these hypotheses combined the following: (i) the hypothesis of all the successful applicants, (ii) the hypothesis of painters, (iii) the Jinshi hypothesis + the hypothesis of applicants and (iv) the hypothesis of all the successful applicants + the hypothesis of painters. Additionally, in order to judge the influence of the mother and the aunt, we implemented an experiment (v) to remove the variables of these characters. Table 11.1 shows the results.

The experiment (vi) with the hypothesis of all the successful applicants + the hypothesis of painters showed the smallest error from the observational patterns. When compared to the experiment (vi) in the same settings, the experiment (v) showed a greater error. This result shows that the hypothesis of the mother and the aunt would play an important role in the model accuracy. On the other hand, those experiments of (i), (ii) with the single hypothesis and (iii) with the hypothesis

Table 11.1 The result of pattern-oriented inverse simulation

No.	Hypothesis	Error (SSE)
(i)	All the successful applicants	51.00
(ii)	Painters	68.75
(iii)	Jinshi, applicants	57.50
(vi)	All the successful applicants, painters	35.25
(v)	All the successful applicants, painters without the influence of the mother and the aunt	48.75

of Jinsh + the hypothesis of applicants showed greater errors. These experiments showed that use of multiple patterns observed by using filters with different natures would enhance the model accuracy.

11.8 Conclusion

This paper described the inverse simulation methods for ABM while introducing model cases. The inverse simulation method demonstrated that it has the natures of inductive inference, deductive inference and generative inference. This paper also introduced that inverse simulation, as the inductive inference method to approximate a model to the actual data, can enhance the model validity by estimating the state variable that could minimise the error by using evolutionary computing. On the other hand, ABM is a computer programme where equivalent deductive functions exist. This fact shows that ABM has the nature of deductive inference. Showing the case where reinforcement learning was conducted, this paper explained that by using this nature, ABM can generatively show how we can reach the balance or the optimised solutions as in an economic model. Introducing pattern-oriented modelling that creates multiple hypotheses in order to conduct a stronger inference, this paper showed that applying inverse simulation to this method makes it possible to build a strong model based on a combination of weak patterns.

It is important for ABM designers to clearly explain whether the objective of their studies is the inductive inference or the deductive inference, or the abduction to discover new hypotheses. People misunderstand this point and make criticisms regarding ABM. In this sense, the expression “simulation” is appropriate for ABM which takes the inductive inference approach. However, the expression “modelling” is more appropriate for ABM that takes the deductive inference approach.

As for other studies regarding the inverse simulation method, the following cases have been proposed: the case that applied the inverse simulation method to feature analysis for good customers in marketing (Takashima et al. 2006), the case that compared error estimation methods for variable calibration (Rand 2012) and the case that showed linking desirable situations that are intentionally created by the model designer can generate any given world (Izumi et al. 2013). These studies can accelerate the attempts from the standpoint of model estimation for ABM, holding high expectations for further development in the future. It has been a few centuries since the scientific method was proposed, while this method has made epoch-making achievements in a variety of scientific fields where this method was adopted. We hope that this paper will serve to promote to validate ABM.

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Chapter 12
Identification of High-Frequency Herding Behavior in the Chinese Stock Market: An Agent-Based Approach

Zhenxi Chen and Thomas Lux

Abstract The existing literature often uses various aggregate measures to track the influence of sentiment on asset prices. Rather than using proxies like volume or cross-sectional dispersion, it might, however, be preferable to estimate a full-fletched model that allows for sentiment formation among investors along with fundamental innovations. This paper estimates one such model proposed by Alfarano et al. (J Econ Dyn Control 32(1):101–136, 2008). We apply the simulated method of moment estimator proposed by Chen and Lux (Comput Econ 2018, https://doi.org/10.1007/s10614-016-9638-4) to investigate the herding behavior in the Chinese stock market using high-frequency data. The asset pricing process is driven by fundamental factors and sentiment change due to idiosyncratic changes of expectations and herding effects. We find evidence of both autonomous switches of sentiment as well as of herding effects in the Chinese stock market. The autonomous switching tends to dominate the herding effect. Both autonomous and herding effects are stronger during the crisis year 2015 than in other periods.

12.1 Introduction

During June to August 2015, the Chinese stock markets (both Shanghai and Shenzhen stock exchanges) experienced a severe downturn. As shown in Fig. 12.1, within three months, the Shanghai Stock Exchange Composite Index (SSE) lost almost half of its market value, dropping from 5178.19 to 2870.71. However, during the time of this crisis, no major negative news was found from the fundamental side. The economic performance of China was considered outstanding compared to the

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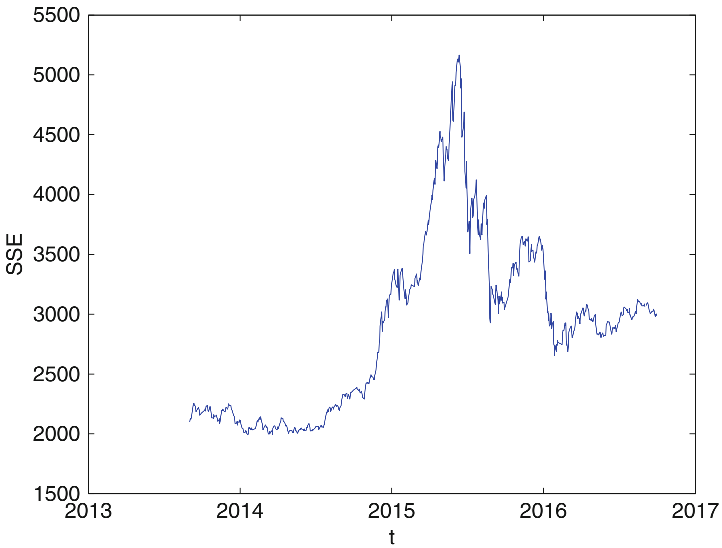

Fig. 12.1 Daily index of Shanghai stock exchange composite

rest of the world, with a growth rate consistently higher than 6%. Therefore, non-fundamental factors such as herding may play an important role in the Chinese stock market.

Herding is defined as investors mimicking the trading behavior of other market players. The extant literature mainly uses aggregate measures to identify herding behavior in financial market. This paper instead uses the micro-founded model developed by Alfarano et al. (2008) to investigate the behavioral sentiment formation in the Chinese stock market at the high-frequency level. We apply the simulated method of moment (SMM) estimator proposed by Chen and Lux (2018) to estimate the pertinent parameters. Evidence is found that at the high-frequency level, behavioral sentiment dynamics explain a non-negligible part of price changes in the Chinese stock market.

Previous literature has mostly used proxies to gauge the relevance of herding. One of the first is the so-called LSV approach developed by Lakonishok et al. (1992). The LSV method defines herding as the excess proportion of net buyers among the group of money managers for a given stock. Bethke et al. (2017) use the LSV herding measure to investigate the dynamics of bond correlations and report that negative investor sentiment causes a flight-to-quality of investors and high bond correlation. Another measure for herding behavior is the cross-sectional standard deviation (CSSD) proposed by Christie and Huang (1995) with the argument that dispersion is expected to be low when individual returns herd around the market average. Li et al. (2017) use a trading volume-based CSSD measure to compare the herding behavior of individual and institutional investors. In a similar spirit to CSSD, Chang et al. (2000) develop a third measure of herding using cross-sectional absolute deviation of returns (CSAD). Using the CSAD measure, Chang and Lin (2015) report that national culture and behavioral pitfalls have an influence on herding, while Economou et al. (2016) find that herding becomes stronger during crisis periods.

Agent-based simulation models (ABMs) provide a way to investigate herding from the perspective of the microlevel considering directly the interactions of agents that are at the heart of this phenomenon (cf. Terano et al. 2003). As one of the first examples of a financial ABM, Kirman (1993) proposes a theoretical model to study information propagation as well as nonrational interactions among agents. The model provides a potential behavioral explanation of the phenomenon of herding and epidemics in financial markets. Lux (1995) formalizes herding behavior in speculative financial markets in an alternative way, and he shows how bubbles and crashes can result as emergent macro phenomena from waves of market sentiment and herding of investors. Takahashi and Terano (2003) consider non-fundamental agents that are characterized by herding, non-standard utility functions adhering to tenets of prospect theory, and overconfidence in their own predictive capabilities. Along the lines of Kirman (1993) and Lux (1995), Alfarano et al. (2008) categorize the behavioral switching of investors into two types: autonomous sentiment changes and imitation of others. The imitative switching corresponds to herding. Based on this micro-founded mechanism, they develop an asset pricing model which is able to provide an analytical avenue to some financial stylized facts like fat tails of returns and the temporal dependence of volatility. Comparing the performance of agent-based models in matching the key stylized facts of financial markets, Mandes and Winker (2016) find that the model of Alfarano et al. (2008) has a relatively better goodness-of-fit than some alternatives.

For the empirical validation of ABM models, the simulated method of moments (SMM) is one of the most popular approaches. Winker et al. (2007) propose an objective function based on moments related to stylized facts of financial markets and use SMM to estimate the parameters of agent-based models in an application to the foreign exchange market. Franke (2009) adopts SMM to estimate the HAM model of Manzan and Westerhoff (2005) for various financial markets. In a subsequent series of papers, Franke and Westerhoff continue this line of research by varying the setting of SMM and assessing the capability of different agent-based models in explaining the stylized facts (Franke and Westerhoff 2011, 2012, 2016). Using SMM to estimate the model of Alfarano et al. (2008), and Jang (2015) reports that social interaction accounts for nearly half of the return volatility of the major foreign exchange rates. Using the same underlying model, Chen and Lux (2018) provide a more systematic analysis of the efficiency of SMM estimators and by and large confirm Jang's result for a larger sample of assets.

Following the implementation of SMM proposed by Chen and Lux (2018), this paper attempts to validate the relevance of herding behavior in the Chinese stock market using high-frequency data with time intervals of 1, 5, 10, and 30 min. We also study the herding behavior of Chinese investors by zooming in on the crisis periods. As it turns out, non-fundamental factors again explain about 50% of the fluctuations of the market.

The rest of the paper is organized as follows. Section 12.2 presents the theoretical model of asset price dynamics driven by fundamental factors and sentiment dynamics. Section 12.3 introduces the estimation methodology and data. Section 12.4 applies the methodology to estimate the parameters of the behavioral model using a range of empirical high-frequency data. Lastly, Sect. 12.5 concludes the paper.

12.2 Theoretical Model

For the stock market in our model, the log price and log fundamental value at time t are denoted by p_t and F_t. The market is populated by two types of traders: fundamentalists and noise traders. Each type of trader has their own trading strategy.

The group of fundamentalists has N_f members each of whom has an average trading volume per transaction V_f. Fundamentalists base their trading decision on their perceived fundamental value. Their excess demand is formulated as:

$$D^f = N_f V_f \left(F_t - p_t\right). \tag{12.1}$$

Fundamentalists will be buyers if the fundamental value is larger than the price and vice versa. That is, they buy underpriced assets and sell overpriced ones. Over a short time interval, F_t is assumed to follow a Brownian motion such that:

$$F_{t+1} = F_t + \sigma_f \cdot e_{t+1}, \tag{12.2}$$

where σ_f is the standard deviation of the innovations of the fundamental value and $e_{t+1} \sim iidN(0, 1)$.

The group of noise traders has N_c members. Each noise trader has an average trading volume per transaction of V_c. A noise trader can be in either an optimistic or a pessimistic state, and then she will buy or sell, respectively. At time t, the number of optimistic noise traders is denoted as n_t, and the corresponding number of pessimistic traders is $N_c - n_t$. We define a sentiment measure $x_t = 2n_t/N_c - 1$ to indicate the relative importance of the two kinds of noise traders. x_t signals a balanced disposition if equal to zero and suggests an optimistic or a pessimistic majority if positive or negative. The disposition of the noise traders is not fixed as a noise trader can switch between the two states. The sentiment dynamics is characterized by time-varying transition rates for a pessimistic trader to become an optimistic one ($\pi^+_{x,t}$) and vice versa ($\pi^-_{x,t}$). These transitions have two components. One is autonomous switching of opinion captured by a Poisson intensity a. The other is switching due to pair-wise communication with another noise trader holding the opposite opinion. This herding component is captured by a coefficient b multiplied by the chance to meet a noise trader with the opposite opinion. The transition rates can be formulated as:

$$\begin{cases} \pi_{x,t}^{+} = (N_c - n_t)(a + bn_t) = (1 - x_t)\left[2a/N_c + b(1 + x_t)\right] N_c^2, \\ \pi_{x,t}^{-} = n_t(a + b(N_c - n_t)) = (1 + x_t)\left[2a/N_c + b(1 - x_t)\right] N_c^2. \end{cases} \tag{12.3}$$

We denote the probability density of x_t by $\omega(x)$. Alfarano et al. (2008) prove that the temporal development of $\omega(x)$ is characterized by the Fokker-Planck or forward Kolmogorov equation:

$$\frac{\partial \omega(x,t)}{\partial t} = \frac{\partial}{\partial x}(A(x)\,\omega(x,t)) + \frac{1}{2}\frac{\partial^2}{\partial x^2}(D(x)\,\omega(x,t)) \tag{12.4}$$

with drift and diffusion terms: $A(x) = -2ax$, $D(x) = 2b\left(1 - x^2\right) + 4a/N_c$.

Given the law of motion Eq. (12.4), the dynamics of x_t can be either simulated directly or approximated via a stochastic differential equation. The time-varying x_t leads to excess demand of noise traders according to

$$D^c = N_c V_c x_t. \tag{12.5}$$

Excess demands of fundamentalists and noise traders drive the dynamics of the stock price.

$$\begin{aligned} \frac{dp_t}{dt} &= \beta\left(D^f + D^c\right) \\ &= \beta\left[N_f V_f (F_t - p_t) + N_c V_c x_t\right], \end{aligned} \tag{12.6}$$

where β is the price adjustment coefficient. Assuming instantaneous market clearing with $\beta \to \infty$, we derive the market-clearing price driven by the fundamental value and the disposition of noise traders at time t:

$$p_t = F_t + \frac{N_c V_c}{N_f V_f} x_t. \tag{12.7}$$

Over the discrete time intervals, the return in the stock market can be defined as the log price changes. Therefore, we have

$$\begin{aligned} r_{t+1} &= p_{t+1} - p_t \\ &= F_{t+1} - F_t + \tfrac{N_c V_c}{N_f V_f}(x_{t+1} - x_t) \\ &= \sigma_f \cdot e_{t+1} + \tfrac{N_c V_c}{N_f V_f}(x_{t+1} - x_t). \end{aligned} \tag{12.8}$$

It can be seen that returns are determined by the change of the fundamental value and the change of noise trader sentiment. Assuming $\frac{N_c V_c}{N_f V_f} = 1$ for simplicity, the vector of parameters $\theta = \left(a, b, \sigma_f\right)$ determines the dynamics of return.

12.3 Methodology and Data

12.3.1 Simulated Method of Moments Estimation

Returns of financial assets are universally characterized by several elementary statistics or moments featuring the typical stylized facts such as fat tails and volatility clustering. These moment statistics usually include the second and fourth moments of the raw returns $E(r^2)$ and $E(r^4)$, in addition to the autocovariance of both raw returns and certain higher powers (such as squared returns) at various lags. We stack moments of interest in a vector $m = (m_1, \ldots, m_n)'$ where m_n is the nth moment condition. For a sample of returns r_t with size L, define the compact variable $z_t = (r_t, r_{t-1}, \ldots, r_{t-L})$. Moments for empirical data are computed as the time average

$$m^{\text{emp}} = \left(1/T_{\text{emp}}\right) \sum_{t=1}^{T_{\text{emp}}} m\left(z_t^{\text{emp}}\right) \tag{12.9}$$

with T_{emp} the sample size of the empirical data. In the same spirit, moments of the simulated data can be computed as:

$$m^{\text{sim}} = (1/T_{\text{sim}}) \sum_{t=1}^{T_{\text{sim}}} m\left(z_t^{\text{sim}}(\theta, \varepsilon_t)\right), \tag{12.10}$$

where $\theta = \left(a, b, \sigma_f\right)$ is the vector of parameters which we want to estimate, ε_t is the joint influence of the Wiener process underlying the fundamental factor and the stochastic elements of the agent-based process of sentiment formation, $z_t^{\text{sim}}(\theta, \varepsilon_t)$ is the simulated L-sample returns based on parameter set θ and noises ε_t, and T_{sim} is the sample size of simulated data. In order to keep simulation variability small, T_{sim} should be a multiple of T_{emp}. Here we define the simulation ratio $R = T_{\text{sim}}/T_{\text{emp}}$ with R as a positive integer. The simulated moments m^{sim} are functions of θ. The goal of moment matching is equivalent to that $h_T = m^{\text{emp}} - m^{\text{sim}}$ should be minimized, and as a result, parameter estimates $\widehat{\theta}$ can be obtained as:

$$\widehat{\theta}_T = \arg\min_{\theta} \left(h_T(\theta)' W_T h_T(\theta)\right), \tag{12.11}$$

where W_T is a positive definite weighting matrix which should reflect the different degrees of precision in the measurement of the different moments. It has been proved by Lee and Ingram (1991) and Duffie and Singleton (1993) that under general regularity conditions, the SMM estimator for θ is asymptotically consistent.

W_T is obtained using the method of Newey-West:

$$W_T = \left(\left(1 + \frac{1}{R}\right)\widehat{\Omega}\right)^{-1}, \tag{12.12}$$

where

$$\begin{cases} \widehat{\Omega} = \Gamma_0 + \sum_{j=1}^{p} \left(1 - \frac{j}{p+1}\right) \left(\Gamma_j + \Gamma_j'\right), \\ \Gamma_j = \frac{1}{T} \sum_{t=j+1}^{T} h_{T,t}(\theta)\, h_{T,t-j}(\theta)', \\ h_{T,t}(\theta) = m\left(z_t^{\text{emp}}\right) - \frac{1}{T_{\text{sim}}} \sum_{t=1}^{T_{\text{sim}}} m\left(z_t^{\text{sim}}(\theta, \varepsilon_t)\right), \\ R = T_{\text{sim}}/T_{\text{emp}}. \end{cases} \tag{12.13}$$

12.3.2 Data

We investigate the herding behavior in the Chinese stock market represented by the Shanghai Composite Index. The high-frequency data (1, 5, 10, and 30 min) are extracted from the WIND database.[1] The sample period is 13 September 2013 to 12 September 2016. Returns for each frequency are calculated by natural log differences. Table 12.1 reports the descriptive statistics of returns under each frequency. Returns under the four frequencies all exhibit non-normal distributions. With the time interval increasing from 1 to 30 min, the mean return increases proportionally. However, the maximum and minimum returns are quite stable, not changing proportionally with the time interval. The variance increases proportionally with the time interval from 5- to 30-min intervals, while there is a large jump from the 1-min to the 5-min intervals. Similar phenomena are observed for the skewness, kurtosis, and Jarque-Bera statistics in that there is an abrupt change from 1 to 5 min, while the values for 5, 10, and 30 min are roughly of the same magnitude. In summary, the statistics do not change proportionally with the time interval.

Table 12.1 Descriptive statistics for returns under each frequency

	1 min	5 min	10 min	30 min
Mean	$1.64 \cdot 10^{-6}$	$8.29 \cdot 10^{-6}$	$1.63 \cdot 10^{-5}$	$5.02 \cdot 10^{-5}$
Maximum	$7.53 \cdot 10^{-2}$	$5.72 \cdot 10^{-2}$	$3.89 \cdot 10^{-2}$	$4.45 \cdot 10^{-2}$
Minimum	$-7.22 \cdot 10^{-2}$	$-6.99 \cdot 10^{-2}$	$-6.60 \cdot 10^{-2}$	$-7.60 \cdot 10^{-2}$
Variance	$8.20 \cdot 10^{-7}$	$6.23 \cdot 10^{-6}$	$1.14 \cdot 10^{-5}$	$3.27 \cdot 10^{-5}$
Skewness	−6.67	−1.90	−1.55	−1.39
Kurtosis	929.89	66.17	36.15	21.88
Jarque-Bera	$6.33 \cdot 10^{9}$	$5.86 \cdot 10^{6}$	$8.11 \cdot 10^{5}$	$8.88 \cdot 10^{4}$
Observations T_{emp}	176697	35099	17557	5851

[1]WIND is a Chinese third party data service provider. Its URL is http://www.wind.com.cn/en/Default.html.

12.4 Empirical Result

This paper in total considers 15 moment conditions including the second and fourth moments of raw return, the autocovariance of raw returns at lag order 1, and autocovariances of squared returns as well as absolute returns at lag orders 1, 5, 10, 15, 20, and 25. These moment conditions are denoted by m_1 to m_{15}, listed in Table 12.2.

Chen and Lux (2018) evaluate four estimators: SMM4 (m_1 to m_4), SMM7 (m_1 to m_7), SMM11 (m_1 to m_{11}), and SMM15 (m_1 to m_{15}). Given the default parameter set for some parameters that have little effect on time series characterization and for the simulation size,[2] we employ these four estimators to estimate the parameters of the model for the four frequencies both for the full sample and for the crisis year 2015.

Following Chen and Lux (2018), we use an exact discrete-event simulation to generate the discretized sentiment trajectories x_t that is the non-fundamental component of the return series. To properly align the different time horizons, we need to choose a basic time unit for the simulations. If the time unit we choose is too large, high-frequency observations with time interval smaller than the basic time unit could not be used. As our data frequencies range from 1- to 30-min interval, we choose 1 min as the time unit for our simulation. With 1 min as a time unit, if we want to estimate synthetic data at the 30-min frequency, we would simulate a time series with 1 min as the basic time unit and then generate the simulated returns on 30-min time intervals by summing up the simulated returns over 30 time steps. According to the theoretical model of Alfarano et al. (2008), for the same normalization of the time unit, we should then expect to obtain similar parameter estimates for different time intervals since the different frequencies correspond to different measurements of moments of the same hypothesized process for which the sampling frequency is properly accounted for.

To assess the weight of fundamental fluctuations in the empirical variance, we define the fundamental weight as

$$\eta = \frac{s \cdot \sigma_f^2}{Var_{\text{emp}}}, \tag{12.14}$$

with $s \geq 1$ the sampling frequency in minutes.

Table 12.2 List of moment condition candidates

m_1	m_2	m_3	m_4	m_5
$E(r_t^2)$	$E(r_t r_{t-1})$	$E(r_t^2 r_{t-1}^2)$	$E\left(r_t^4\right)$	$E(\lvert r_t\rvert\,\lvert r_{t-1}\rvert)$
m_6	m_7	m_8	m_9	m_{10}
$E(r_t^2 r_{t-5}^2)$	$E(\lvert r_t\rvert\,\lvert r_{t-5}\rvert)$	$E(r_t^2 r_{t-10}^2)$	$E(\lvert r_t\rvert\,\lvert r_{t-10}\rvert)$	$E(r_t^2 r_{t-15}^2)$
m_{11}	m_{12}	m_{13}	m_{14}	m_{15}
$E(\lvert r_t\rvert\,\lvert r_{t-15}\rvert)$	$E(r_t^2 r_{t-20}^2)$	$E(\lvert r_t\rvert\,\lvert r_{t-20}\rvert)$	$E(r_t^2 r_{t-25}^2)$	$E(\lvert r_t\rvert\,\lvert r_{t-25}\rvert)$

[2] $N_c = 100$, $N_f = 100$, $V_c = 1$, $V_f = 1$, and $R = T_{\text{sim}}/T_{\text{emp}} = 4$.

Table 12.3 reports the estimation results using 1 min as the time unit in the simulation together with the result of the so-called J-test for the goodness-of-fit of the empirical moments by the simulated ones. Only a few cases pass the J-test at 10% significance level, which implies that in most cases the null hypothesis that the empirical moments could have been generated by the Alfarano et al. (2008) model can be rejected. The three parameters a, b, and σ_f are, however, all significant for the majority of the cases. The SMM15 estimator for the 30-min frequency encounters a convergence problem, and no stable estimate is observed in this case. From the descriptive statistics of Table 12.1, the variance exhibits a disproportional change from the 1-min frequency to other frequencies. For the SMM estimators except for SMM4, each has similar estimates with values within one order of magnitude across frequencies except for the 1-min frequency, especially for parameters a and σ_f. At least for the time frequencies of 5–30 min, these results are roughly consistent with an underlying model like that of Alfarano et al. (2008) for which the parameters could be recovered for data at any level of time aggregation.

Estimation results of all the SMM estimators for all frequencies tend to have $a > b$, indicating that autonomous switching dominates the herding dynamics. In a few cases, the parameter b indeed converges to the lower bound imposed in the estimation so that in these cases there would only be unsystematic fluctuations of sentiment (noise trading) and no systematic herding. Estimates of the three parameters a, b, and σ_f in the crisis year 2015 tend to be larger than their counterparts of the full sample, indicating that investors have a higher tendency of both autonomous changes of sentiment and herding behavior during the crisis period. Meanwhile, the fundamental factor also exhibits larger fluctuations in the crisis period. In the decomposition of the empirical variance, the fundamental factor has a weight in the full sample of around 0.5, comparable to the one in the crisis year 2015, suggesting that non-fundamental sentiment factors account for around 50% for the fluctuations of returns all the time.

We also evaluate combining moment conditions of multiple frequencies into a single SMM estimation using the basic time unit. For example, when 1 min is set as the time unit, for a particular SMM estimator such as SMM4, we would include the four moments of each of the four frequencies to have a total of $16(= 4 * 4)$ empirical moments for the estimation. We use the 1-min time unit to simulate a price time series, based on which we can calculate the simulated return time series for each frequency and generate the corresponding 16 simulated moments. As sample size differs for different frequencies, it would be difficult to calculate the off-diagonal part of the variance-covariance matrix of the moments. Therefore, for simplicity, we use the inverse of the diagonal part of the variance-covariance matrix of the moments as a weighting matrix.

Table 12.4 reports the estimation results of each SMM estimator for the case of multiple frequencies. Similar to the results shown in Table 12.3 for the single-frequency time series, the three parameters a, b, and σ_f are significant in all the cases. The estimated parameters again tend to have larger values in the crisis year 2015. When we look at the fundamental weight in the empirical variance reported in Table 12.5, estimates from SMM4 have very small weights of fundamentals in

Table 12.3 J-test and estimated parameters for 1 min as a unit time. Values in parentheses are the asymptotic p-value for the J-test and standard errors for the three parameters. *, **, and *** stand for 10%, 5%, and 1% significance level. η is the weight of the fundamental factor in the empirical variance. Note that 10^{-9} is the lower boundary set in the estimation

		Full sample					Crisis year 2015				
		J	$a * 10^3$	$b * 10^3$	$\sigma_f * 10^3$	η	J	$a * 10^3$	$b * 10^3$	$\sigma_f * 10^3$	η
SMM4	1 min	209.24***	$1.51 \cdot 10^{-4}$	$1.00 \cdot 10^{-9}$	0.49***	0.30	162.32***	$1.27 \cdot 10^{-3}$	$1.00 \cdot 10^{-9}$	0.76*	0.33
		(0)	$(1.15 \cdot 10^{-3})$	$(6.90 \cdot 10^{-8})$	(0.16)		(0)	$(7.11 \cdot 10^{-3})$	$(5.00 \cdot 10^{-9})$	(0.41)	
	5 min	2.93*	$7.05 \cdot 10^{-5}$***	$6.65 \cdot 10^{-3}$***	0.52***	0.22	9.32***	$1.29 \cdot 10^{-2}$	$4.22 \cdot 10^{-4}$	0.90	0.32
		(0.09)	$(2.27 \cdot 10^{-6})$	$(3.27 \cdot 10^{-4})$	(0.07)		(0.00)	$(8.58 \cdot 10^{-3})$	$(4.38 \cdot 10^{-4})$	(0.56)	
	10 min	6.25**	$1.41 \cdot 10^{-4}$	$1.00 \cdot 10^{-9}$	0.92***	0.74	3.21*	$1.94 \cdot 10^{-5}$**	0.14***	1.31***	0.78
		(0.01)	$(1.30 \cdot 10^{-3})$	$(2.30 \cdot 10^{-8})$	(0.08)		(0.07)	$(7.88 \cdot 10^{-6})$	(0.03)	(0.07)	
	30 min	6.46**	$2.14 \cdot 10^{-2}$*	$2.08 \cdot 10^{-5}$***	$1.00 \cdot 10^{-9}$	0.00	6.23*	$5.78 \cdot 10^{-4}$***	0.13***	1.74***	1.44
		(0.01)	$(1.26 \cdot 10^{-2})$	$(4.63 \cdot 10^{-6})$	(14.21)		(0.01)	$(6.06 \cdot 10^{-6})$	$(1.50 \cdot 10^{-3})$	(0.19)	
SMM7	1 min	232.94***	$9.78 \cdot 10^{-5}$	$6.01 \cdot 10^{-6}$	0.45***	0.25	173.93***	$1.45 \cdot 10^{-5}$***	$1.23 \cdot 10^{-4}$***	0.63***	0.23
		(0)	$(3.03 \cdot 10^{-3})$	$(5.09 \cdot 10^{-5})$	(0.02)		(0)	$(1.35 \cdot 10^{-6})$	$(3.15 \cdot 10^{-5})$	(0.03)	
	5 min	17.78***	$4.32 \cdot 10^{-3}$***	$1.00 \cdot 10^{-9}$	0.85***	0.59	14.69***	$9.59 \cdot 10^{-3}$***	$1.00 \cdot 10^{-9}$	1.18***	0.55
		(0.00)	$(2.76 \cdot 10^{-4})$	(0)	(0.03)		(0.01)	$(5.94 \cdot 10^{-4})$	(0)	(0.04)	
	10 min	15.04***	$1.93 \cdot 10^{-3}$***	$1.00 \cdot 10^{-9}$	0.81***	0.58	10.54**	$2.45 \cdot 10^{-4}$***	$6.14 \cdot 10^{-5}$***	1.12**	0.57
		(0.00)	$(2.39 \cdot 10^{-4})$	$(1.00 \cdot 10^{-9})$	(0.03)		(0.03)	$(2.09 \cdot 10^{-5})$	$(4.55 \cdot 10^{-6})$	(0.05)	
	30 min	9.98**	$2.03 \cdot 10^{-3}$***	$4.77 \cdot 10^{-7}$***	0.80***	0.59	7.95*	$8.95 \cdot 10^{-4}$***	$2.23 \cdot 10^{-5}$***	0.99***	0.47
		(0.04)	$(1.89 \cdot 10^{-4})$	$(4.20 \cdot 10^{-8})$	(0.08)		(0.09)	$(4.40 \cdot 10^{-5})$	$(2.99 \cdot 10^{-6})$	(0.11)	
SMM11	1 min	272.31***	$1.68 \cdot 10^{-5}$***	$5.91 \cdot 10^{-5}$***	0.43***	0.23	184.36***	$2.38 \cdot 10^{-4}$***	$1.64 \cdot 10^{-4}$***	0.68***	0.26
		(0)	$(3.58 \cdot 10^{-6})$	$(6.26 \cdot 10^{-6})$	(0.01)		(0)	$(1.54 \cdot 10^{-5})$	$(9.17 \cdot 10^{-6})$	(0.03)	
	5 min	23.42***	$3.57 \cdot 10^{-3}$***	$1.00 \cdot 10^{-9}$	0.84***	0.57	19.33**	$8.36 \cdot 10^{-3}$***	$3.86 \cdot 10^{-6}$***	1.14***	0.50
		(0.00)	$(1.48 \cdot 10^{-4})$	(0)	(0.03)		(0.01)	$(3.34 \cdot 10^{-4})$	$(1.53 \cdot 10^{-7})$	(0.03)	
	10 min	15.51**	$1.88 \cdot 10^{-3}$***	$1.00 \cdot 10^{-9}$	0.82***	0.59	10.83	$2.43 \cdot 10^{-4}$***	$6.19 \cdot 10^{-5}$***	1.12**	0.57
		(0.05)	$(1.64 \cdot 10^{-4})$	$(1.00 \cdot 10^{-9})$	(0.03)		(0.21)	$(8.08 \cdot 10^{-6})$	$(3.84 \cdot 10^{-6})$	(0.05)	

	30 min	17.78**	$1.31 \cdot 10^{-3}$***	$3.00 \cdot 10^{-9}$	0.72***	0.48	6.78	$3.06 \cdot 10^{-4}$***	0.12***	1.14**	0.61
		(0.02)	$(1.71 \cdot 10^{-4})$	$(2.00 \cdot 10^{-9})$	(0.08)		(0.56)	$(7.23 \cdot 10^{-6})$	$(1.66 \cdot 10^{-3})$	(0.06)	
SMM15	1 min	267.00***	$1.60 \cdot 10^{-5}$***	$6.09 \cdot 10^{-5}$***	0.46***	0.26	185.80***	$2.49 \cdot 10^{-3}$***	$1.30 \cdot 10^{-4}$***	0.69***	0.27
		(0)	$(9.17 \cdot 10^{-7})$	$(5.53 \cdot 10^{-6})$	(0.01)		(0)	$(1.08 \cdot 10^{-4})$	$(5.31 \cdot 10^{-6})$	(0.02)	
	5 min	28.28***	$6.88 \cdot 10^{-5}$***	$5.99 \cdot 10^{-5}$***	0.81***	0.53	23.39**	$2.74 \cdot 10^{-3}$***	$8.08 \cdot 10^{-5}$***	1.17***	0.55
		(0.01)	$(4.18 \cdot 10^{-6})$	$(2.69 \cdot 10^{-6})$	(0.03)		(0.02)	$(1.47 \cdot 10^{-4})$	$(6.67 \cdot 10^{-6})$	(0.04)	
	10 min	19.01*	$1.93 \cdot 10^{-3}$***	$1.00 \cdot 10^{-9}$	0.81***	0.58	13.77	$2.44 \cdot 10^{-4}$***	$5.25 \cdot 10^{-5}$***	1.13***	0.58
		(0.09)	$(9.30 \cdot 10^{-5})$	(0)	(0.03)		(0.32)	$(8.30 \cdot 10^{-6})$	$(2.02 \cdot 10^{-6})$	(0.04)	
	30 min	Singular									

Table 12.4 J-test and estimated parameters with 1 min as unit of time. Values in parentheses are the asymptotic p-value for the J-test and standard errors for the three parameters. *, **, and *** stand for 10%, 5%, and 1% significance level

	Full sample				Crisis year 2015			
	J	$a*10^3$	$b*10^3$	σ_f*10^3	J	$a*10^3$	$b*10^3$	σ_f*10^3
SMM4	581.89***	$4.50\cdot10^{-6}$***	$3.60\cdot10^{-3}$***	0.21***	600.97***	$1.13\cdot10^{-5}$***	$1.55\cdot10^{-3}$***	0.50***
	(0.00)	$(3.48\cdot10^{-7})$	$(1.27\cdot10^{-6})$	(0.02)	(0.00)	$(2.03\cdot10^{-7})$	$(3.56\cdot10^{-6})$	(0.02)
SMM7	2933.21***	$1.05\cdot10^{-3}$***	$2.41\cdot10^{-4}$***	0.88***	1447.15***	$1.69\cdot10^{-3}$***	$5.76\cdot10^{-4}$***	1.17***
	(0.00)	$(1.12\cdot10^{-5})$	$(1.27\cdot10^{-6})$	(0.00)	(0.00)	$(8.22\cdot10^{-6})$	$(4.43\cdot10^{-6})$	(0.00)
SMM11	5282.65***	$4.02\cdot10^{-4}$***	$4.26\cdot10^{-4}$***	0.81***	2403.61***	$9.96\cdot10^{-6}$***	$9.51\cdot10^{-4}$***	1.10***
	(0.00)	$(7.36\cdot10^{-6})$	$(1.22\cdot10^{-5})$	(0.00)	(0.00)	$(4.10\cdot10^{-7})$	$(1.16\cdot10^{-5})$	(0.00)
SMM15	7593.30***	$7.06\cdot10^{-4}$***	$4.36\cdot10^{-4}$***	0.79***	3504.00***	$1.80\cdot10^{-3}$***	$8.34\cdot10^{-4}$***	1.07***
	(0.00)	$(2.72\cdot10^{-6})$	$(1.59\cdot10^{-6})$	(0.00)	(0.00)	$(5.52\cdot10^{-6})$	$(1.84\cdot10^{-6})$	(0.00)

Table 12.5 Weight of fundamental factor in the empirical variance

	Full sample				Crisis year 2015			
	1 min	5 min	10 min	30 min	1 min	5 min	10 min	30 min
SMM4	0.06	0.04	0.04	0.04	0.14	0.10	0.11	0.12
SMM7	0.94	0.62	0.67	0.71	0.79	0.54	0.62	0.65
SMM11	0.80	0.53	0.58	0.60	0.70	0.48	0.55	0.58
SMM15	0.77	0.50	0.55	0.58	0.66	0.45	0.52	0.55

explaining the empirical variances, while the rest of the three SMM estimators have weights above 0.5. The weights are comparable in the full sample and the crisis year. For all the SMM estimators except for SMM4, estimates of a, b, and σ_f are similar across the SMM estimators with values of a and σ_f close to the ones from the estimations based on single-frequency data. The fundamental weights are also similar across the SMM estimators. A drawback of our estimations on the high-frequency data is the significant rejection of the underlying data generating model by the J-test which is different from results obtained at the daily level for various financial time series as reported in Chen and Lux (2018). The major reason for this difference might, however, be the large sample size when using intra-daily data that should allow to reject any specific model of asset price dynamics.

12.5 Conclusion

There are a number of empirical approaches adopting various aggregate measures for herding behavior that lack micro-foundation and, therefore, are not fully reliable for differentiating between fundamental factors and the influences of sentiment on asset prices. This paper takes an alternative avenue for identification of sentiment dynamics in asset returns. Rather than resorting to such proxies, we apply the heterogeneous agents model of Alfarano et al. (2008) which uses a bottom-up approach to formalize herding behavior.

We use the SMM method of Chen and Lux (2018) to assess the degree of herding behavior in the Chinese stock market using high-frequency data. Using 1 min as the basic time unit, we simulate various moments to match the empirical ones at different frequencies and find significant switching behavior of investors. Zooming in on the crisis period, both the autonomous switching parameter and the herding parameter tend to be larger, indicating that investors have a higher tendency to change their mind. The higher switching of investors may suggest that investors became nervous or fell into panic such that their judgements became fragile during the crisis periods. In addition, the fundamental factor is also found to have been subject to larger fluctuations during the crisis period.

The fluctuations of the fundamental value accounts for around 50% of the volatility of the market returns in both the normal and crisis periods. This means that the Alfarano et al. (2008) model attributes a large share of market volatility to non-fundamental factors such as switching of investors between optimistic and pessimistic sentiment.

We believe that estimation will play an important role in the future development of the ABM literature. While early contributions have mostly derived interesting insights on the self-organization and emergence of macroscopic patterns from distributed activity in simple toy models, the next generation of models will have to be confronted rigorously with empirical data. Recent literature has developed a rich toolbox of methods to validate agent-based models, to assess their goodness-of-fit and compare the performance of alternative ABMs (cf. Lux and Zwinkels 2018).

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Chapter 13
A Data Analysis Study on Factors of the Pedestrian Flows in Two Different Underground Malls Using Space Syntax Measures: Case Comparisons in Nagoya, Japan

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Abstract This paper discusses factors of the pedestrian flows in two different underground malls by conducting multiple regression analysis with visibility measures based on space syntax theory and store proximity measures, etc. Both case studies are treated as a "coupled case" with regard to the directly neighboring spaces, i.e., the ground level sidewalks. They are separated into two complementary analyses and the results from both cases compared. In addition, this research will be examined as a "closed case," limited exclusively to the underground mall area and compared with the coupled case.

Keywords Space syntax theory · Underground mall · Factor analysis · Spatial configuration · Pedestrian flows

13.1 Introduction

13.1.1 Research Background and Objectives

Space syntax theory (SST), initiated by Bill Hillier (Hillier and Hanson 1984), presents a methodology to analyze spatial structure and has been used to evaluate the characteristics of different urban and built environments. SST defines movement and occupation as the fundamental functions of a space, and the measures used are configurational and calculate the relation between spaces within a system. Nearly

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a decade later, the idea of natural movement (Hillier et al. 1993) arose, referring to the distribution of movement as a consequence of spatial configuration. The factors influencing the presence of pedestrians in an underground urban environment are different to those we find in the typical ground level sidewalks or those factors that affect the spaces inside buildings. The weather conditions, scale of the city, subway systems, street layout, intensity of retail activities, etc. all influence the presence of pedestrians, sometimes in a positive way by boosting natural movement or in a negative way by decreasing it. Several papers have explored the relations between the SST measures and pedestrians, but only a few papers have analyzed underground malls.

For this purpose, this paper discusses factors of the pedestrian flows by conducting multiple regression analysis with visibility measures based on SST and store proximity measures, etc. on two different underground malls located in Nagoya City: one in Sakae, the CBD area of the city with extensive department stores and offices, and the other in Nagoya station (hereinafter called Meieki), the largest terminal station in the Chubu region of Japan and surrounded by many office and commercial buildings. Both case studies will consider "coupled case" scenarios with the directly neighboring spaces, i.e., the ground level sidewalks which pedestrians can access via the entrance or exit stairs of the underground mall and the basements and ground floors of adjacent department stores. They will be separated into two complementary analyses, and the results from both cases will be compared. In addition, this research will be examined in a "closed case," limited exclusively to the underground mall area, keeping in mind its connections with the subway entrances or exits but excluding connections to adjacent buildings and the street level.

Through this method, it is intended to identify the influence of neighboring spaces on the presence of pedestrians inside underground malls and what measures exert a stronger influence on pedestrian flow when evaluating such underground malls.

13.1.2 Prior Research on the Factor Analysis of Pedestrians Applying SST Measures

Prior to our research, we examined earlier domestic reports published by the Architectural Institute of Japan and the City Planning Institute of Japan, along with overseas reports presented at the International Space Syntax Symposium, the International Seminar on Urban Forum, and other events, all of which concern factor analysis of pedestrians applying SS measures.

In the 1990s, the correlation between pedestrians and SS measures was reported overseas by Hillier et al. and in Japan by Hanazato et al. (1991). With regard to the factor analysis of pedestrian numbers, in 2003 an overseas report by Desyllas et al. presented an analysis in which SS measures were included as a factor in addition to the distance from the nearest station, intensity of land use, and pedestrian lane width (Desyllas et al. 2003). Later, Özer et al. reported factor analysis of pedestrians in Istanbul and concluded SS measures were a secondary factor (Özer and Kubat 2007). In Japan, in 2005 Araya et al. analyzed pedestrian numbers using both SS measures and the distance from the nearest station; SS measures were found to be the primary factor and the distance from the nearest station the secondary factor (Araya et al. 2005). Afterward, Ota et al. reported that factor analysis of pedestrian numbers applying SS measures was effective even when comparing different points of time (Ota et al. 2015).

An analysis of a multilevel case was reported by Afroza et al. overseas, whereas in Japan, Ueno et al. analyzed the multilevel facilities of a station and reported SS measures were the primary factor (Afroza et al. 2007; Ueno et al. 2009). From among those reports on underground space, the same subject as our research, Okamoto et al. analyzed the correlation between SS measures and pedestrian numbers in the Nagoya Station underground mall complex (Okamoto et al. 2013) and Ota et al. analyzed the Sakae Station underground mall complex as a closed case (Ota et al. 2017). They used SS measures to analyze the pedestrian numbers and found the distance from the nearest station or ticket gate to be the primary factor and SS measures as secondary or later factors; however, SS measures were adopted in statistical tests. They clarified that in the Nagoya Station underground closed space, a combination of the "shortest distance from the nearest ticket gate" and "centrality of the underground space" influenced pedestrian flow and the degree of hustle and bustle in the underground space.

The factor ranking in the prior reports shows that the distance from the nearest station (ticket gate) tended to be ranked higher; however, some reports do give SS measures a higher ranking. Especially in the study of underground malls, it is important to examine and compare a number of stations because each station has its own characteristics.

13.2 Case Study Area: Sakae and Nagoya Station Underground Mall

13.2.1 Outline of the Case Study Area

The Sakae underground mall, located in the center of Nagoya CBD, measures approx. 83,199 m^2. Its development started in 1957, together with the first subway line project in Nagoya (Higashiyama line), and continued expanding until 2002. Hosting more than 320 shops, it connects the exits of three different subway lines together with several commercial buildings surrounding the mall, especially in the southwest area.

The Meieki underground mall is situated around the Nagoya Station, another CBD pole of the city. It also started developing with the subway, in 1957, and expanded together with the increase of nearby commercial buildings reaching approx. 83,345 m^2 in the final extension (1976). The T-shaped underground complex connects two different subway lines, three railways, and several commercial buildings in the surrounding area. With a daily average of 1.14 million passengers (2008), it is the largest terminal station in the Chubu region.

13.2.2 Survey of Pedestrian Flows in the Case Study Area

In our case study, we performed the survey as follows.

1. Defining gate locations:

   In accordance with the layout, the number of counting locations differed between study cases, but both had a higher number of gate locations inside the underground mall, as our main focus was to observe the behavior of pedestrians within that specific space: Sakae had 55 gate locations in the underground space and 30 gate locations on the ground level, while the Meieki area had 50 gate locations underground and 30 on the ground floor.

2. Gate count survey:

   As our study focused on underground mall users, it was essential to exclude as many commuters as possible, and with this in mind, we selected weekdays at the end of September 2016 and a 2 h period outside the rush hours between 13:30 and 15:30. The gate count on the ground level was limited to pedestrians and excluded cyclists. In the case of Meieki, the pedestrian data was reused for the purpose of re-evaluating the past results, from this different point of view.

Figure 13.1 shows the survey spots and results in the case study area.

13.3 Candidate Explanatory Variables

13.3.1 Space Syntax Theory and Proposed Measures

SST is a general term for spatial analysis techniques proposed in the early 1980s by Hillier et al. of University College London. This research used SS measures based on visibility graph analysis of SST.

For visibility graph analysis, the surveyed area was divided into grids, and a focus was given to the link between the central points of the grids to define each quantitative measure. From among them, the following four measures were studied: connectivity (CNT), visual step depth (VSD), shortest distance (metric shortest path length: MSP), and integration value (IV). Each measure is outlined below.

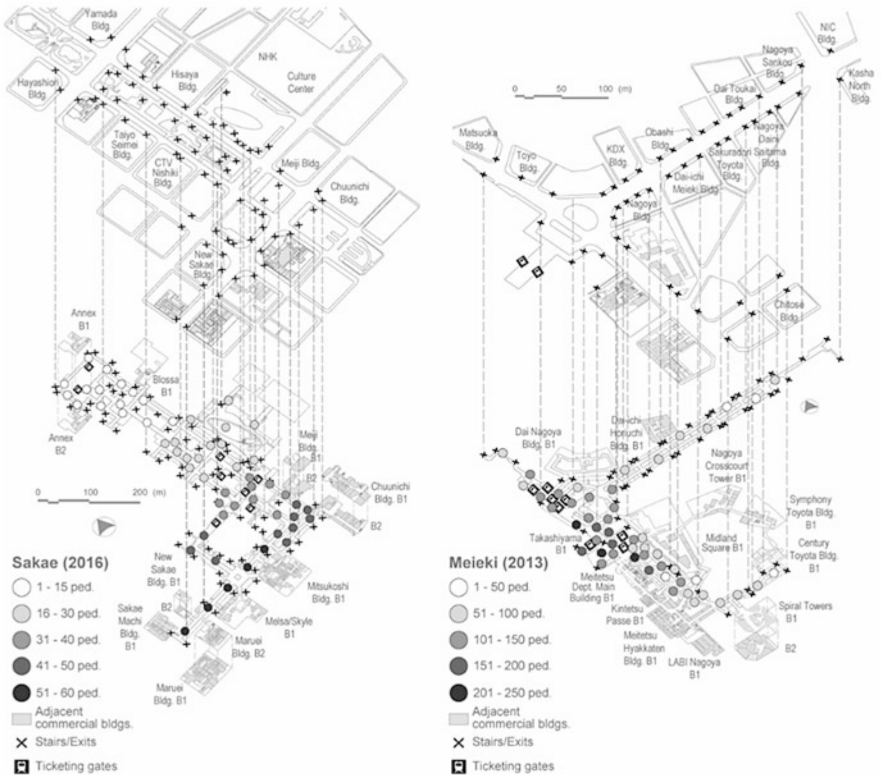

Fig. 13.1 The underground mall in Sakae and Nagoya station with pedestrian counts

CNT is the total number of grids directly visible from a grid; a higher value indicates a broader visible area from the grid, and the grid is visible from many directions.

VSD is the number of perspective lines (depth) and represents the least number of steps between two specified grids; a step is a visual direction change made when moving from one grid to another grid. When a specific grid is assumed to be zero steps, any area visible from that grid is assumed to be one step. A smaller value indicates visually easy movement from a grid. In VSD, the concept of distance is abstracted.

MSP is a measure to find the Euclidean distance between vertices and is unusual among SST measures, the majority of which are dependent on the spatial topological distance. A smaller value shows the relevant grid is located closer to a specific grid.

IV is a reciprocal of a value obtained by standardizing the average depth. To find an IV, a relative asymmetry (RA) first needs to be found. A topological distance from one point to another point on a graph is regarded as depth, and the average of the depths from one point to all other points is the mean depth (MD), and from this value, the RA is found (Expression 13.1). Since the RA value is dependent on

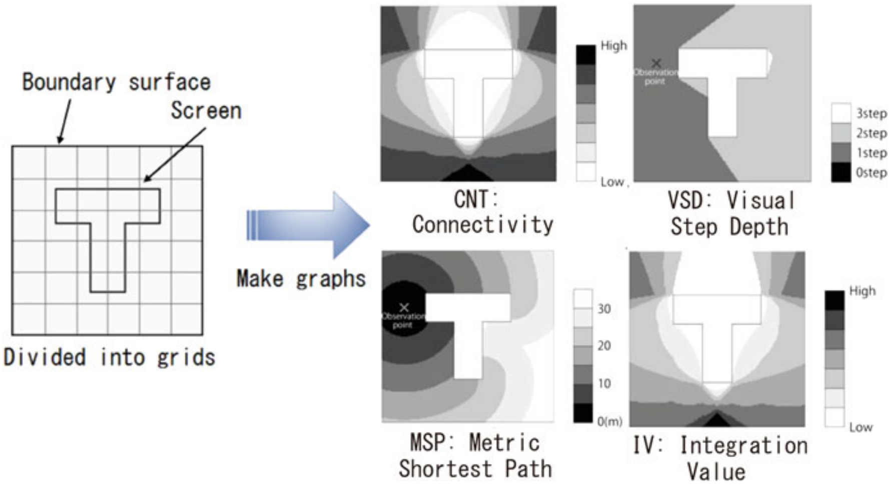

Fig. 13.2 Images of space syntax measures

the vertex to be analyzed, by standardizing the RA to find a real relative asymmetry (RRA) as shown in Expression 13.3, it becomes possible to compare spaces with differing numbers of vertices. Moreover, to make it easier to understand, a reciprocal is found and this is an IV (Expression 13.4). The IV has depth as a denominator; therefore, a higher value indicates the relevant grid has a higher degree of centrality in the whole closed area.

Figure 13.2 shows an image of each SS measure.

$$\mathrm{RA} = \frac{2\,(\mathrm{MD}-1)}{k-2} \tag{13.1}$$

$$D_k = \frac{2\left[k\left\{\log_2\left(\frac{k+2}{3}\right)-1\right\}+1\right]}{(k-1)\,(k-2)} \tag{13.2}$$

$$\mathrm{RRA} = \frac{\mathrm{RA}}{D_k} = \frac{(\mathrm{MD}-1)\,(k-1)}{\left[k\left\{\log_2\left(\frac{k+2}{3}\right)-1\right\}+1\right]} \tag{13.3}$$

$$\mathrm{IV} = \frac{1}{\mathrm{RRA}} \tag{13.4}$$

13.3.2 *Spatial Distribution of the Space Syntax Measures in the Case Study Area*

In this research and analysis, the whole area of the four underground malls in the Sakae district was assumed to be one closed case. Depthmap analysis software was used to calculate each measure value in the visibility graph analysis, and grids were set at one-meter intervals. When a two-meter or more high or wide screen exists, it was assumed that passages beyond the screen were not visible.

In the analysis of the underground mall, the following pairs of candidate explanatory variables were prepared from the space syntax measures: visual step depth to station (VSDS) and metric shortest path to station (MSPS) as proximity measures to the nearest station ticket gate, VSDA and MSPA as proximity measures to adjacent facilities, and VSDAS and MSPAS as proximity measures to the nearest station ticket gates or adjacent facilities. For the integration values (IV), a global integration value (GIV) using an average depth of the whole underground area and a local integration value LIV 3 with calculation stopping at Depth 3 were prepared.

The spatial distribution of each measure was examined. The spatial distribution of the visibility depth VSDS and the shortest distance MSPS to the nearest station ticket gate showed a smaller value around the center of any area where the ticket gates converged (Figs. 13.3 and 13.4). In the spatial distribution of the visibility depth VSDA, it is noticeable that the values decreased at the area where adjacent facilities are concentrated (Fig. 13.5). From the spatial distribution of the global integration value (GIV), it was found that a spot with a higher centrality had a higher value (Fig. 13.6).

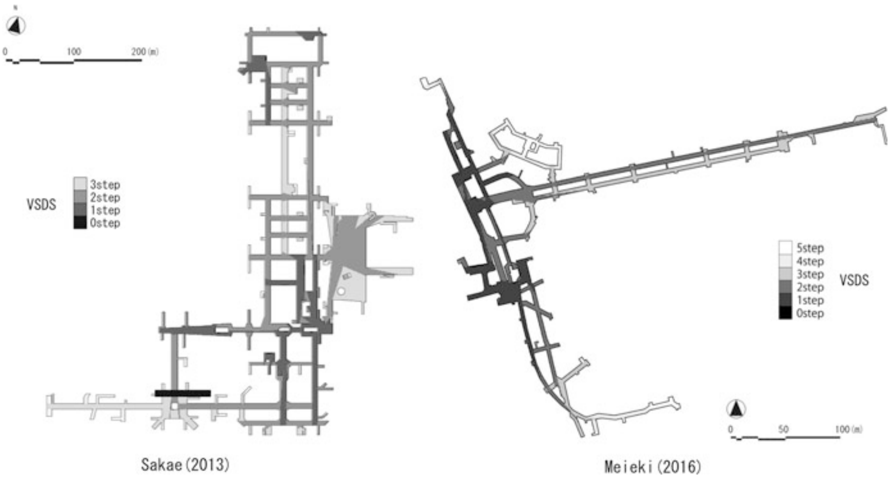

Fig. 13.3 The spatial distribution of the VSDS

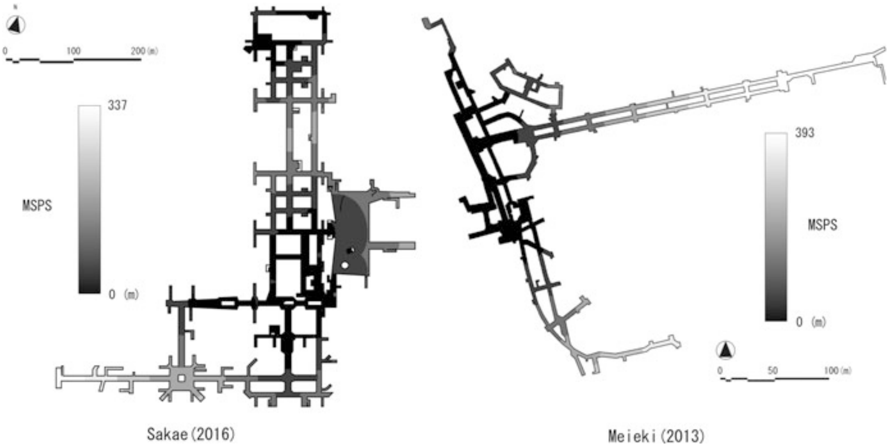

Fig. 13.4 The spatial distribution of the MSPS

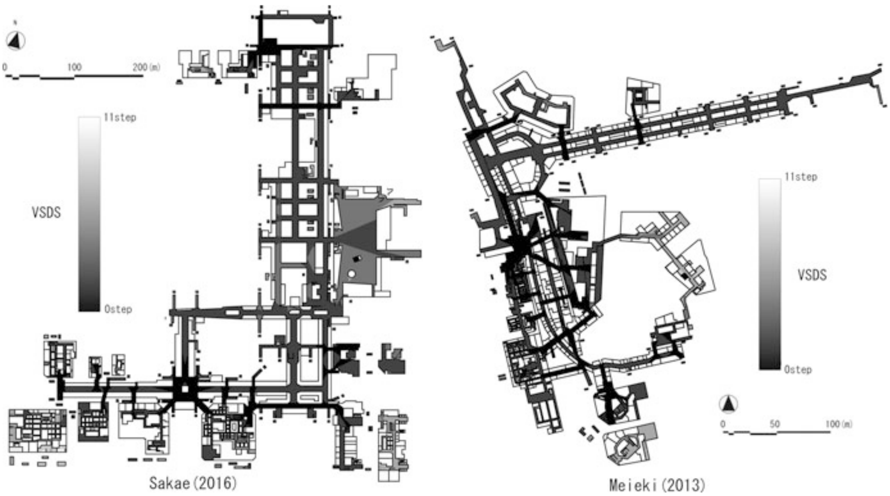

Fig. 13.5 The spatial distribution of the VSDA

13.3.3 Survey of Store Proximity in the Sakae and Nagoya Underground Mall

As variables relating to the store proximity in the underground mall, this research newly developed and used a TCD (tenant count depth) and a TCM (tenant count metric). TCD is the number of visible stores in the underground mall that can be visually observed (Depth 1) from a pedestrian number survey spot. A higher TCD value indicates a higher number of stores that are easy to visually locate. TCM is

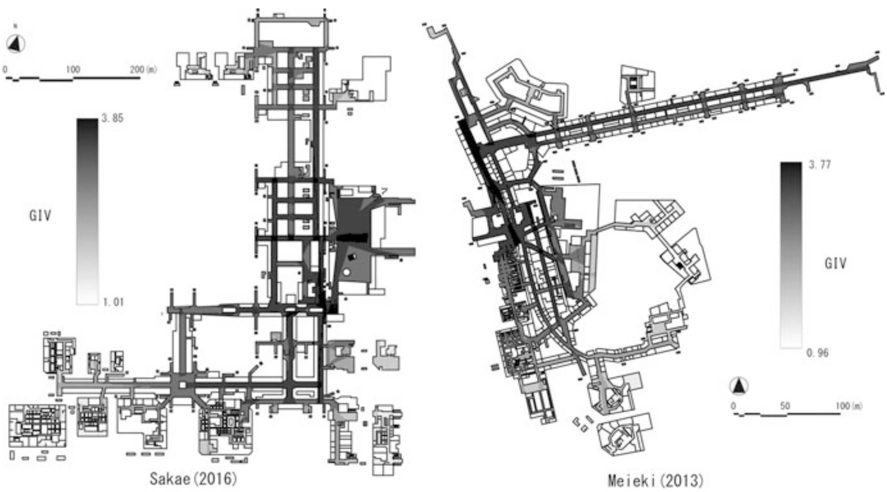

Fig. 13.6 The spatial distribution of the GIV

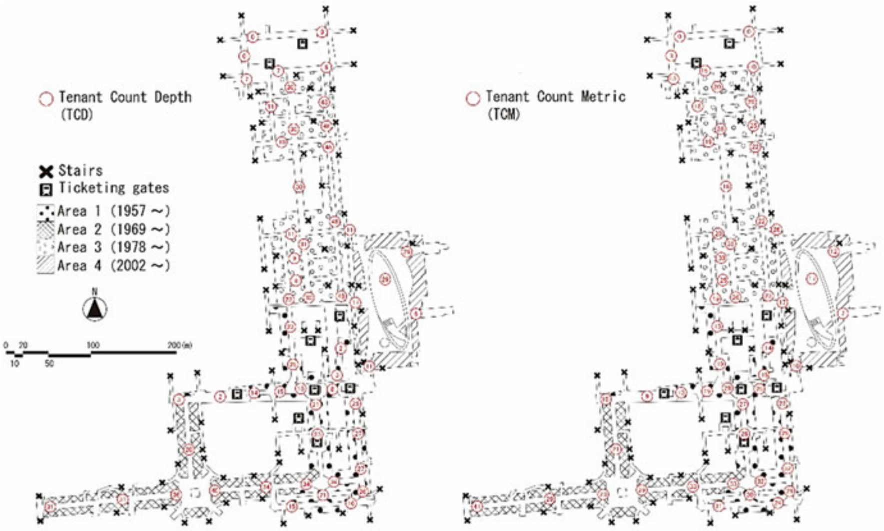

Fig. 13.7 The spatial distribution of the TCD and TCM in the Sakae underground mall

the number of stores within a 50-m radius from a pedestrian number survey spot. A higher TCM value indicates a higher number of stores at a close distance.

Figure 13.7 shows TCD and TCM values in the Sakae underground mall.

It allows us to confirm that in the Sakae underground mall, the TCD values were high in long passages. This is the same tendency as CNT; therefore, it is possible to consider the values were affected by visible areas. The TCM values were high at the area from the central part to the south side, and it is possible to consider that areas with a high centrality tended to show relatively high TCM values.

13.4 Analysis of the Relation Between Underground Spatial Configurations and Pedestrian Flows by Using Space Syntax Measures

13.4.1 Sakae Underground Mall Coupled Case Study

A correlation matrix and VIFs were created for the pedestrian numbers surveyed at the 55 spots in the Sakae underground mall and the candidate factor variables (Table 13.1).

Table 13.1 shows the highest correlation with MSPA (−0.311), followed by TCM (0.290), VSDS (−0.242), and TCD (0.236), which indicates a high correlation with measures relating to the proximity to adjacent facilities. However, the absolute value of all correlations was lower than 0.4, and a strong correlation was not shown.

Table 13.1 also shows VIFs between candidate explanatory variables. To avoid multicollinearity, from combinations with a VIF exceeding 2, a candidate explanatory variable showing the highest correlation with the pedestrian numbers was selected and others were rejected.

Table 13.1 Correlation matrix between pedestrian numbers and candidate explanatory variables

VIF / Correlation	Pedest-rian	Conne-ctivity	Ticket gate		Adjacent facility		Integration value		Tenant count	
		CNT	VSDS	MSPS	VSDA	MSPA	GIV	LIV3	TCD	TCM
Pedestrian		1.003	1.062	1.009	1.059	1.107	1.014	1.005	1.059	1.214
CNT	-0.052		1.123	1.029	1.087	1.002	1.069	2.661	1.214	1.008
VSDS	-0.242	0.331		1.361	1.014	1.015	1.010	1.302	1.153	1.040
MSPS	0.092	0.168	0.515		1.065	1.098	1.040	1.139	1.208	1.214
VSDA	-0.235	-0.283	-0.116	-0.247		1.718	1.040	1.101	1.000	1.021
MSPA	-0.311	-0.041	0.121	-0.299	0.646		1.020	1.002	1.045	1.037
GIV	0.116	0.254	-0.097	-0.196	0.197	0.141		1.201	1.144	1.119
LIV3	-0.068	0.790	0.482	0.349	-0.303	-0.043	0.409		1.314	1.035
TCD	0.236	0.420	0.364	0.415	-0.014	-0.207	0.355	0.489		1.453
TCM	0.290	-0.087	0.195	0.420	-0.145	-0.189	0.327	0.184	0.558	

Table 13.2 Results of the multiple regression analysis

Model			Correlation coefficient		t-value	AIC	Statistical test	
			Multi	Single				
(1)	Single	MSPA	−0.311		−2.380	629.743	**	
(2)	Multi	VSDS	0.424	−0.242	−2.800	626.452	***	***
		TCD		0.236	2.769			***
(3)	Multi	VSDS	0.505	−0.242	−3.162	623.099	***	***
		TCD		0.236	2.948			***
		VSDA		−0.235	−2.283			**

*** <1%, ** <5%

From among combinations of CNT (the correlation with the pedestrian numbers (hereinafter, the same) was −0.052) with LIV3 (−0.068), LIV3 use was selected.

Based on the pedestrian numbers and eight candidate explanatory variables, regression analysis using the stepwise method was conducted up to three variables, and Models (1), (2), and (3) were obtained and found to have a significant difference at a level of 5%.

However, the goodness of fit ranking according to the information criterion was Models (3), (2), and (1). Table 13.2 shows the regression analysis results of the models.

According to the AIC, Model (3) is the best model of fit, and correlation coefficient of the model is 0.505. In the intensity order of factors, VSDS (*t*-value: −3.162), TCD (2.948), and VSDA (−2.283) were adopted.

13.4.2 Nagoya Station Underground Mall Coupled Case Study

A correlation matrix and VIFs were created for the pedestrian numbers surveyed at the 50 spots in the Nagoya station underground mall and the candidate factor variables (Table 13.3).

Table 13.3 shows the highest correlation with MSPS (−0.598), followed by GIV (0.491), VSDS (−0.486), and MSPA (−0.198), which indicates a high correlation with measures relating to the proximity measures to the nearest station ticket gate. Besides the measures, the absolute value of GIV was also more than 0.4, and a slightly strong correlation was shown.

Table 13.3 also shows VIFs between candidate explanatory variables. From among combinations of CNT (the correlation with the pedestrian numbers (hereinafter, the same) was −0.090) with LIV3 (−0.056) and TCD (−0.187), TCD use was selected. From among combinations of VSDS (−0.486) with GIV (0.491), GIV use was selected.

Based on the pedestrian numbers and seven candidate explanatory variables, regression analysis using the stepwise method was conducted up to two variables, and Models (1), (2), and (3) were obtained and found to have a significant difference at a level of 5%.

Table 13.3 Correlation matrix between pedestrian numbers and candidate explanatory variables

VIF / Correlation	Pedestrian	Connectivity	Ticket gate		Adjacent facility		Integration value		Tenant count	
		CNT	VSDS	MSPS	VSDA	MSPA	GIV	LIV3	TCD	TCM
Pedestrian		1.008	1.309	1.555	1.001	1.041	1.318	1.003	1.036	1.030
CNT	-0.090		1.006	1.169	1.052	1.340	1.164	3.965	3.715	1.005
VSDS	-0.486	-0.077		1.615	1.031	1.000	2.216	1.116	1.013	1.025
MSPS	-0.598	0.380	0.617		1.003	1.353	1.247	1.024	1.346	1.031
VSDA	-0.027	0.222	-0.173	0.053		1.325	1.009	1.023	1.039	1.227
MSPA	-0.198	0.504	0.006	0.511	0.496		1.003	1.199	1.191	1.256
GIV	0.491	0.376	-0.741	-0.445	-0.093	0.055		1.498	1.035	1.117
LIV3	-0.056	0.865	-0.323	0.154	0.151	0.408	0.577		1.997	1.000
TCD	-0.187	0.855	0.113	0.507	0.195	0.400	0.183	0.707		1.028
TCM	0.171	-0.071	-0.155	-0.173	-0.430	-0.452	0.324	-0.016	0.164	

Table 13.4 Results of the multiple regression analysis

Model			Correlation coefficient		*t*-value	AIC	Statistical test	
			Multi	Single				
(1)	Single	VSDS	−0.486		−3.852	524.760	**	
(2)	Single	MSPS	−0.598		−5.163	516.147	*	
(3)	Multi	MSPS	0.648	−0.598	−3.810	512.965	***	***
		GIV		0.491	2.265			**

*** <1%, ** <5%

However, the goodness of fit ranking according to the information criterion was Models (3), (2), and (1). Table 13.4 shows the regression analysis results of the models.

According to the AIC, Model (3) is the best model of fit, and correlation coefficient of the model is 0.648. In the intensity order of factors, MSPS (*t*-value: −3.810) and GIV (2.265) were adopted.

Table 13.5 The number of daily passengers in Sakae and Nagoya station

Sakae Total	Three lines in Sakae					
	Higashiyama	Meijyo	Meitetsu			
135,033	77,876	36,975	20,182			
Nagoya Total	Six lines in Nagaoya					
	Tokaido	Meitetsu	Higashiyama	Kintetsu	Sakuradori	Aonami
608,970	205,070	142,066	132,572	61,917	52,487	14,858

13.4.3 Comparison Between Sakae and Nagoya Station Underground Mall Case Study

In the best model in Sakae, VSDS, VSDA, and TCD were adopted in the intensity order of factors. VSDS is the distance from the nearest station ticket gate; VSDA and TCD are the variables related with the store. All three variables have a visible concept.

On the other hand, in the best model in Meieki, MSPS and GIV were adopted. The distance from the nearest station ticket gate is the metric short path but not the visual step. GIV, the integration value representing the centrality of a street, was adopted but not in Sakae.

Comparing the Sakae and Nagoya station as case studies, Sakae station has three lines and Nagoya station double that with six lines. The number of daily passengers in Sakae is 135,000 and in Nagoya, 608,000, about 6 times as many (Table 13.5). Both stations are in the downtown area, but it is considered that people may go to Sakae station for shopping, eating, etc. but use Meieki mainly for transfer. Therefore, pedestrian flows to the stores for shopping, eating, etc. are strongly related to the proximity to the stores in Sakae station. Meikei, as a transfer station, has pedestrian flows to locations distant from the nearest station ticket gate and has high centrality of streets because of natural movement.

It is the characteristics of each station that give rise to differing pedestrian flows, but in both station cases, space syntax measures are adopted.

13.4.4 Comparison Between the Coupled and Closed Case Studies

In the closed case, an analysis targeting only the underground malls in Sakae and Meieki was conducted, and the analyzed area was limited exclusively to the underground mall area, keeping in mind its connections with the subway entrances or exits but excluding any connection to adjacent buildings and the street level.

In Sakae, the number of VSDS and VSDA as explanatory variables was not changed from the coupled to the closed case. The multi-correlation coefficient was improved from 0.505 to 0.507, and the AIC was from 623.099 to 623.013 because the number of TCD had changed a little.

In Meieki, the number of MSPS as the explanatory variable was not changed from the coupled to the closed case. The multi-correlation coefficient dropped from 0.648 to 0.628, and the AIC was from 512.965 to 515.129 because GIV was adopted at a level of 10%. Therefore, GIV was adopted in the coupled case and was fitter than the closed case, which does not include the ground level sidewalks.

13.5 Conclusion

This paper discussed factors of the pedestrian flows by conducting multiple regression analysis with visibility measures based on SST and store proximity measures, etc. in two different underground malls located in Nagoya City: one in Sakae, the CBD area of the city, and the other in Nagoya station, the largest terminal station in the Chubu region of Japan. Both case studies are treated as a "coupled case" with regard to the directly neighboring spaces, i.e., the ground level sidewalks providing pedestrian access via the entrance or exit stairs of the underground mall, and the basements and ground floors of adjacent department stores.

They were separated into two complementary analyses and the results from both cases were compared.

In addition, this research was examined as a "closed case," limited exclusively to the underground mall area.

1. Sakae underground mall coupled case study

According to the AIC, the correlation coefficient of the best model is 0.505. In the intensity order of factors, VSDS (t-value: −3.162), TCD (2.948), and VSDA (−2.283) were adopted.

2. Nagoya underground mall coupled case study

According to the AIC, the correlation coefficient of the best model is 0.648. In the intensity order of factors, MSPS (−3.810) and GIV (2.265) were adopted.

3. Comparison between the Sakae and Nagoya station underground mall case study

In the factors of the best model in Sakae, VSDS is the distance from the nearest station ticket gate and VSDA and TCD are the variables related with the store. And all three variables have a visible concept but not metric. On the other hand, in factors of the best model in Meieki, the distance from the nearest station ticket gate is the metric short path, but not the visual step and GIV; an integration value representing the centrality of streets was adopted but not in Sakae. It is considered that the characteristics of each station caused this result.

4. Comparison between the coupled and closed case study

The number of VSDS and VSDA as explanatory variables was not changed from the coupled to closed case in Sakae. The multi-correlation coefficient was improved slightly. The number of MSPS as the explanatory variable was not changed from the coupled to closed case in Meieki. The multi-correlation coefficient and AIC were worse because GIV was adopted at a level of 10%. Therefore, GIV was adopted as fitter in the coupled case, rather than the closed case, which does not include the ground level sidewalks.

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Chapter 14
A Study on Agent Modeling of Tourist Evacuation Behaviors in an Earthquake: A Case Study of an Evacuation Simulation of Himeji Castle

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Abstract It is an urgent issue to ensure safety of tourists under an earthquake. How do tourists behave under the disaster? This study focuses on tourists' evacuation behavior who don't have enough knowledge of evacuation sites and routes. This study shows an agent modeling technique using a sampling survey of the web-based questionnaire considering the information behaviors and the earthquake experiences and a tourist evacuation agent model using this technique. We analyze the tourists' evacuation behavior using samples of 1086 respondents who made the domestic trip from 20 to 69 years old collected by the web survey in November 2016. The results were summarized into four orientation categories: transport information, safety confirmation, personal safety, and balanced. Next, when two groups, one group with and one without experience of a great earthquake, were compared using four groups, a significant difference was found in any age and sex of each group. Further, this study uses decision tree analysis to model evacuation behavior rules incorporating information behaviors and shows a tourist evacuation simulation using the tourists' evacuation behavior rules. The results confirm an agent modeling technique using sampling survey and decision tree analysis, and a tourist evacuation behavior agent model incorporating information behaviors by the agent modeling technique is enabled.

Keywords Agent modeling · Evacuation behavior · Information behavior · Earthquake experience · Decision tree analysis

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14.1 Introduction

We, the Japanese live on the plate boundary and have a frequent earthquake. Since such a grand condition, we are preparing for coping with the earthquake from childhood. On the other hand, in the case of the out of the town, even for the Japanese, it is hard to make a quick evacuation. This kind of evidence showed at the time of the Great East Japan Earthquake on March 11, 2011. Furthermore, rumors on the social media made our confusions and anxieties.

Discussions to ensure the safety of tourists in the immediate aftermath of an earthquake have only just started, and to date, there has been little evacuation behavior research concerning tourists in an earthquake. Especially, since tourists generally do not have a good knowledge of a neighborhood or the location of evacuation sites, they try to obtain information through smartphones or other information devices. Accordingly, in any discussion on the spatial behaviors of evacuees in an earthquake, behaviors resulting from information received by evacuees (from now on, information behaviors) should be considered. In other words, in the modeling of evacuation simulations as well, it is necessary to consider information behaviors.

This research aims to propose an agent modeling technique combined with a sampling survey and a tourist evacuation behavior agent model extended to allow consideration of information behaviors in an earthquake. In this paper, we carry out intensive research for the tourist behavior through the web-based questionnaire of the information activity.

The rest of the paper is organized as follows: Sect. 14.2 discusses the backgrounds of the research and related works; Sect. 14.3 briefly summarizes the gathered data on the target mail order company; Sect. 14.4 describes the analytics of the data and presents analytical results, and Sect. 14.5 gives some concluding remarks and future work.

14.2 Related Work

This chapter describes the related work for the evacuation behavior. We sort our primary focus on the tourist evacuation behaviors in an earthquake into (a) ordinal evacuation behavior, (b) information search behavior through the media, and (c) the earthquake experiences, respectively.

First, we describe related work of evacuation behaviors. This field of work is roughly divided into the following criteria: the evacuation behaviors through field experiments (Furukawa et al. 2016; Sato et al. 2015; Tange et al. 2016) and surveys (Cui et al. 2013; Matsubayashi and Nakahata 2015; Nishino et al. 2016; Ogasawara et al. 2013; Sakai et al. 2014; Takada et al. 2016), the evaluation of evacuation route (Ogawa et al. 2014; Ogawa et al. 2012), the evacuation guiding method or the evacuation guiding information (Furukawa et al. 2016; Kinugasa et al. 2012; Sakuma et al. 2017; Sato et al. 2015), and the agent-based modeling (Fukuda et al.

2016; Kinugasa et al. 2012; Kitahara et al. 2013). Regarding research of evacuation behavior by information, many types of research of the information provided with verbal communication (Kuwasawa et al. 2015; Matsushima et al. 2014; Sato et al. 2015) use agent-based modeling. Further, many types of research focus on information provision and evacuation guidance with SNS (social network service) and IoT (Internet of Things) (Fujihara and Miwa 2013; Hoshino et al. 2016; Ishii et al. 2008; Jeong et al. 2009; Langner and Kray 2014; Osaragi and Tsuchiya 2017; Shibata et al. 2017). However, no research on evacuation with the agent model consider information gathering by SNS or smart media. Regarding the research of earthquake experiences, many types of research describe the relationship between the disaster experience and the disaster prevention consciousness (Hamada et al. 2005; Shaw et al. 2004). Some research tried to clarify the relationship between the considerable earthquake experience and the evacuation destination selection (Nomura et al. 2013) or psychological condition at the time of evacuation (Kuroda 1969).

As stated above, many previous types of research conduct evacuation agent-based modeling, but they do not consider information behaviors and earthquake experiences. It is a novel method of this study to show an agent modeling technique incorporating information behaviors and the earthquake experiences through the web-based questionnaire and tourist evacuation agent model using the technique.

14.3 Analysis Concerning Prioritized Factors in Tourist Evacuation Behaviors by Using the Survey Data

14.3.1 Sampling Survey Data

To understand our research background, this research was carried out based on the sampling survey data concerning tourist evacuation behaviors in an earthquake. The sampling survey was conducted among people from all over Japan who had an experience of domestic travel, and by the population composition ratio of Japan, 1086 samples were collected (Table 14.1, Fig. 14.1). This research used the survey data taken from the answers to Questions 1, 2, and 5 to carry out analyses.

14.3.2 Analysis of Those Factors Given Priority in Earthquake Evacuation Behaviors

Q. 1 asked respondents: "Whatfactors are most important to you to take action immediately after an earthquake?" They were then requested to assess the following seven factors and to distribute the weight (total: 100) to the importance of certain types of information or facilities, and the results are given in Table 14.2.

Table 14.1 Survey overview of the domestic tourist

Date of survey	14 November 2016
The scope of the survey	Nationwide men and women of from 20 to 69 years old (who made the domestic trip last year)
The number of valid responses	1086 (divide into eight regions, allocate gender and age proportion to population composition ratio)
Survey method	Web survey using the survey form
Survey form	Q1. Factors of emphasis on evacuation behavior at the time of disaster
	Q2. Criteria of importance in route selection at the time of disaster
	Q3. Reliability of medium at the time of the disaster
	Q4. Factors of the home return decision at the time of the disaster
	Q5. Experience of past earthquake

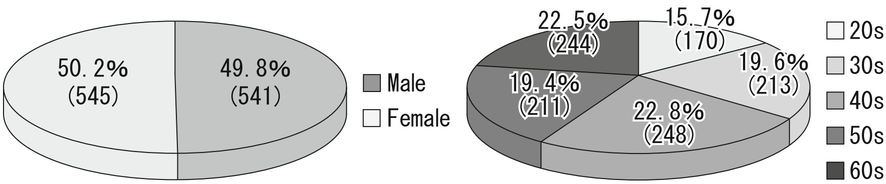


Fig. 14.1 Attributes of the responders

1. I want to know the degree of imminent danger.
2. Light to see my surroundings is important.
3. I want to know the number of people in the vicinity.
4. I want to know if public transport is running.
5. I want to confirm the safety of family members and friends who are in my vicinity during the earthquake.
6. I want to use my smartphone.
7. I want a place to sit and rest.

Cluster analysis was conducted for the response results, and by the orientation of evacuation behaviors, the respondents were classified into four groups. For cluster analysis, k-means clustering was used.

Figure 14.2 shows the weighted average of each factor for each group, obtained from the analysis results, and which factor was particularly important for each group, namely, Group A, public transport information; Group B, confirmation of the safety of family members and friends; Group C, personal safety/imminent danger; and Group D, no significant differences among the factors. Then, by the evacuation behavior orientation, these results were summarized into four orientation categories: transport information, safety confirmation, personal safety, and balanced (Table 14.3).

Table 14.2 Answers of emphasis factors on evacuation behavior

Important factors	Average weight	SD	Minimum value	Maximum value
Surrounding situation 1 (persona safety)	31.28	20.62	0	100
Surrounding situation 2 (brightness)	7.06	7.12	0	50
Number of people around	4.95	5.65	0	40
Traffic information on the return train and bus	17.64	15.96	0	100
Confirmation of safety of family and friends	24.87	19.43	0	100
Is it possible to use smartphones?	10.15	9.32	0	100
Surrounding situation 3 (space)	4.06	6.34	0	60

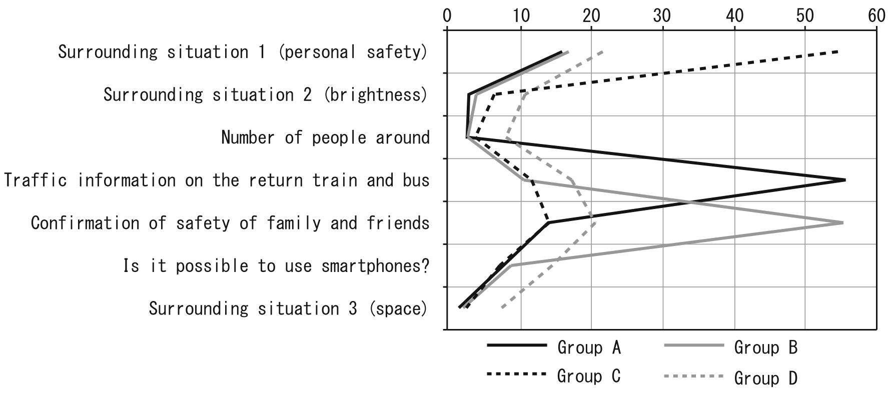


Fig. 14.2 Average weight of factor by group

Table 14.3 Classification of tourists according to the orientation of evacuation behavior

Group	Intentions	Contents.
A	Traffic information emphasis oriented	A group that emphasizes traffic information on the train and bus on the way back
B	Emphasis on safety confirmation	A group that emphasizes confirmation of the safety of family members and friends
C	Safety-oriented	The group focused on safety
D	Balance-oriented	A group that emphasizes seven factors in a balanced manner

Moreover, to sort out characteristics for each classified group, the answers to Q. 5 were used to clarify the composition of each group. Q. 5 asked whether respondents had experienced any of the past five Japanese significant earthquakes; they were also asked to give their individual level of the seismic intensity (Table 14.4).

Table 14.4 Results of answers to questions about past earthquake experience

	Experience seismic intensity								Never experienced ever
	1	2	3	4	5 minus	5 plus	6 minus	Over 6 plus	
January 1995 great Hanshin-Awaji earthquake	4.3%	4.2%	8.4%	11.5%	4.7%	2.5%	1.0%	3.5%	59.9%
	(47)	(46)	(91)	(125)	(51)	(27)	(11)	(38)	(650)
October 2004 Niigata prefecture Chuetsu earthquake	5.7%	4.8%	5.3%	4.4%	2.2%	0.6%	0.1%	0.1%	76.7%
	(62)	(52)	(58)	(48)	(24)	(7)	(1)	(1)	(833)
March 2011 great East Japan earthquake	3.9%	4.8%	10.4%	12.4%	15.5%	10.4%	4.2%	4.6%	33.8%
	(42)	(52)	(113)	(135)	(168)	(113)	(46)	(50)	(367)
April 2016 Kumamoto earthquake	7.8%	5.1%	3.8%	2.4%	0.8%	0.7%	0.7%	0.6%	74.4%
	(85)	(55)	(41)	(26)	(9)	(8)	(8)	(7)	(808)
October 2016 Tottori prefecture central earthquake	8.3%	5.2%	3.8%	0.8%	0.5%	0.3%	0.3%	0.2%	72.4%
	(90)	(57)	(41)	(9)	(5)	(5)	(3)	(2)	(786)

Some samples were shown in ( )

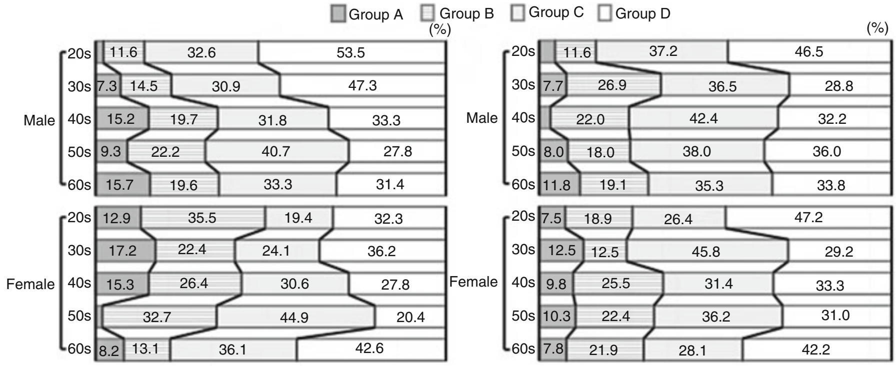


Fig. 14.3 The proportion of each group by sex, age, and earthquake experience (left, the experience of the major earthquake; right, no experience of a significant earthquake, ever)

Based on the results, it was assumed that evacuation behaviors in an earthquake would vary depending on whether the respondent had experienced an earthquake at an individual level of five weak or higher seismic intensity (from now on, great earthquake). Accordingly, the respondents were divided into two categories: one group with and one without the experience of a great earthquake as summarized in Fig. 14.3. When these two groups were compared using Fig. 14.3, a significant difference was found in men in their 40s in Group A, women in their 20s in Group B, women in their 30s in Group C, and men in their 30s in Group D.

14.3.3 Analysis of Route Selections by Group

Next, using the answers to Q. 2, route selections were analyzed for each group classified in Sect. 2.2. Q. 2 asked respondents: "Which route will you take to leave the place where you experienced the earthquake?" They were then requested to assess and distribute the weight (total: 100) to the following eight choices, and the results are given in Table 14.5.

1. I will take the route to my original destination decided before the earthquake.
2. I will return via the route I have taken.
3. I will take the route directed by the authorities and signs.
4. I will take the route instructed by a smartphone.
5. I will follow the route taken by many other people.
6. I will take a route that few other people are taking.
7. I will take a main route.
8. I will take a side route.

Table 14.5 Results of answers on criteria emphasize importance in route selection

	Average weight	Standard deviation	Minimum value	Maximum value
The road toward the destination	13.81	20.23	0	100
Back to the way came through	9.97	14.08	0	100
The direction indicated by the leader or sign	36.60	26.33	0	100
The road that the smartphone ordered	4.63	8.33	0	100
The way with a busy traffic	12.75	13.61	0	100
The way with less traffic	2.53	6.15	0	80
Wide or big street	18.23	18.15	0	100
Narrow street	1.46	4.82	0	100

Table 14.6 Average weight of importance in route selection by group

	A	B	C	D
The road toward the destination	24.39	12.53	14.24	11.26
Back to the way came through	13.60	8.51	8.99	10.78
The direction indicated by the leader or sign	34.13	40.44	40.79	30.99
The road that the smartphone ordered	2.76	3.84	2.98	7.19
The way with a busy traffic	10.12	12.38	12.09	14.33
The way with less traffic	1.10	2.06	2.16	3.56
Wide or big street	13.13	19.73	17.85	19.11
Narrow street	0.76	0.49	0.89	2.78

Using the response results, the weight averages for the route selections were summarized for each group (Table 14.6). The table shows that all groups placed top priority on "taking the route directed by the authorities . . . " When the averages were examined by the group, "taking the route to my original destination . . . " of Group A showed a significant difference compared with other groups. Concerning other route selections, no significant difference was found among the groups.

14.4 Rule Extraction from Decision Tree Analyses

14.4.1 Survey of Tourist Evacuation Behaviors in Assumed Earthquake Situations

To extract tourist evacuation behavior rules incorporating information behaviours in an earthquake, a scenario was assumed using the seven factors in the sampling survey described in Sect. 14.2. Respondents were asked to imagine themselves in the immediate aftermath of an earthquake, under the seven factors shown in Table 14.7. They were then asked: "Under these conditions which behaviour are you most likely to choose from the following four options?"

1. Move to another location.
2. Move and continue to collect information.
3. Remain in the same place.
4. Remain in the same place and collect information.

For example, in surrounding situation 1 (personal safety/imminent danger), there are two criteria: safe or not safe. Therefore, in this scenario survey, respondents gave answers for 128 situations derived from the seven factors and two criteria. Then, decision tree analysis was conducted for this response data to extract agent evacuation behavior rules.

14.4.2 Using Decision Tree Analysis to Extract Agent Evacuation Behavior Rules

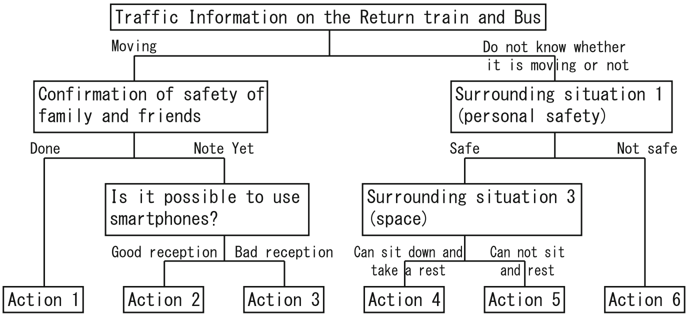
Decision tree analysis is a data mining technique in which a tree-shaped model is used to analyze factors, and from the analysis results, a borderline is sought and prediction made. In this research, the rpart package of the statistical analysis software R was used for analysis. Figure 14.4 shows the evacuation behavior model diagram obtained from the decision tree analysis and the degree of influence (Gini coefficient) of each factor. In the model diagram in the upper part of Figs. 14.4 and 14.5, seven factors of the scenario survey were laid out, and those with the higher degrees of influence were arranged from the top, and consequently, behaviors finally diverged into six, and the behavior to be taken for each situation is predicted by a probability. For example, in a situation where public transport is running, the safety of family members and friends has not been confirmed, and smartphones can be used; it is possible to predict behavior with the following probabilities: move to another place, 0.75, or remain in the same place, 0.25. Moreover, concerning the seven factors in the lower part of Fig. 14.4, when a focus was given to the ranking of the degree of influence, it was found that they can correspond to the weight average of each factor in the groups classified in Sect. 14.2.

Table 14.7 Outline of the assumed investigation

Question examples		
· Surrounding situation 1 (personal safety): not safe		
· Surrounding situation 2 (brightness): sufficiently bright		
· Number of people around: more than usual		
· Traffic information on the return train and buses: do not know whether it is operating or not		
· Confirmed the safety of family and friends: done		
· Use smartphone: good reception		
· Surrounding situation 3 (space): cannot sit down and rest		
The most natural behaviors when the factors shown on the left → (answers from the choices of four action)		
Factors	Level	
Surrounding situation 1 (personal safety)	0. Safe	1. Not safe
Surrounding situation 2 (brightness)	0. Bright	1. Dark with no light
Number of people around	0. More than useful	1. Less than usual
Traffic information on the return train and bus	0. Moving	1. Do not know whether it is moving or not
Confirmation of safety of family and friends	0. Finished	1. Not yet
Is it possible to use smartphones?	0. Good reception	1. Bad reception
Surrounding situation 3 (space)	0. Can sit down and take a rest	1. Cannot sit and rest
Choices of behavior		
1. Move to another location 2. Collect information while moving		
3. Stay on the spot 4. Stay on the spot and gather information		

14.4.3 Generating Typical Example Samples According to Each Group's Orientation

By using decision tree analysis to extract evacuation behavior rules as described in Sect. 14.4.2, typical example samples corresponding to the orientation of each group classified in Sect. 14.3 were generated from the scenario survey results. Figure 14.2 allows us to interpret the evacuation behavior rules shown in Fig. 14.4 as typical examples of the group that prioritized public transport information; therefore, in the same way, typical example samples were generated for the remaining three groups. Figure 14.5 shows Gini coefficients of the degrees of influence of the factors in the decision tree analysis.



Choices of behavior	Probability					
	Action 1	Action 2	Action 3	Action 4	Action 5	Action 6
Move to another location	0.75	0.75	0.00	0.00	0.00	0.00
Collect information while moving	0.00	0.00	0.88	0.00	0.63	1.00
Stay on the spot	0.25	0.25	0.00	0.00	0.00	0.00
Stay on the spot and gather information	0.00	0.00	0.13	1.00	0.38	0.00

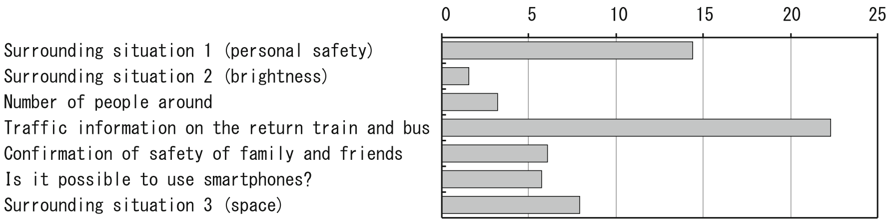


Fig. 14.4 Example of evacuation behavior rule obtained by decision tree analysis (traffic information emphasis oriented): above, evacuation behavior model; bottom, influence of each factor on evacuation behavior (Gini coefficient)

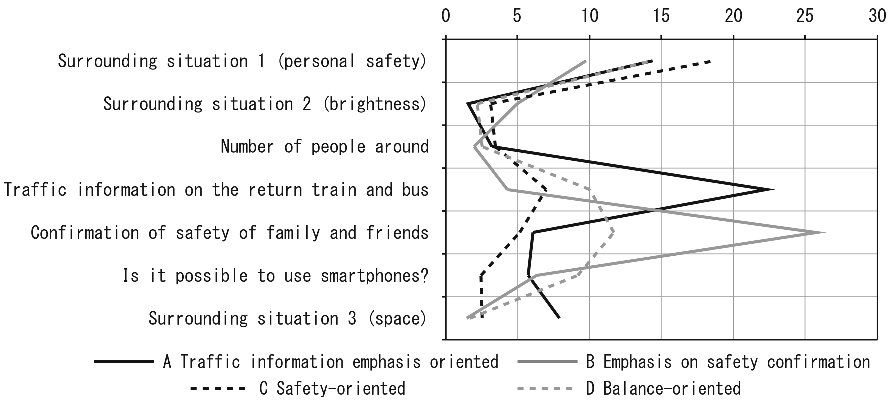


Fig. 14.5 Factor effect degree in typical sample generated by decision tree analysis (Gini coefficient)

14.5 Case Study: Evacuation Simulations of the Himeji Castle

14.5.1 Design of the Evacuation Simulation

This research used SOARS (spot-oriented agent role simulator) to conduct simulations. Firstly, from among the paths in Himeji Castle, any direct paths to the castle tower were implemented in the simulation as a route network (Fig. 14.6). Tourist agents entered the castle site via the only entrance/exit at a rate of 0.55 agents/second, and after the occurrence of an earthquake, agents were not allowed to enter and only allowed to leave the castle. In addition, according to the gate width, the inflow was restricted, and 0.5 agents/ms were set for normal conditions, and 1.5 agents/ms were set for the time after the earthquake. The walking speed was set to 0.5 m/second while sightseeing and 1.5 m/second after the earthquake, and when smartphone use was possible after the earthquake, 0.75 m/second was set for the behavior to move and continue to collect information.

Next, the previously mentioned group classification by the evacuation behavior orientation and the agent evacuation behavior rules incorporating information behaviors were implemented in the agent behavior algorithm (Fig. 14.7). During the time from the occurrence of the earthquake up to the completion of the evacuation, agents repeated evacuation behaviors shown in Fig. 14.7.

14.5.2 Setting Simulation Cases

As shown in Tables 14.8 and 14.9, this research sets four simulation cases by modifying the four factors. Three of them were hugely influential on evacuation behaviors: confirmation of the safety of family members and friends, public transport information, and the possible use of smartphones. The fourth was the

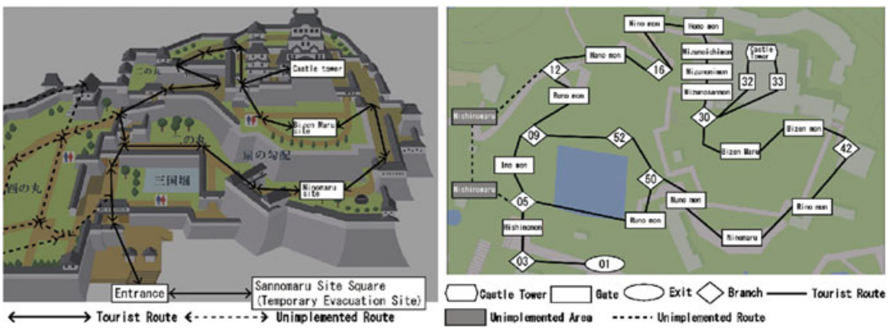


Fig. 14.6 Network path of Himeji Castle and simulation network path

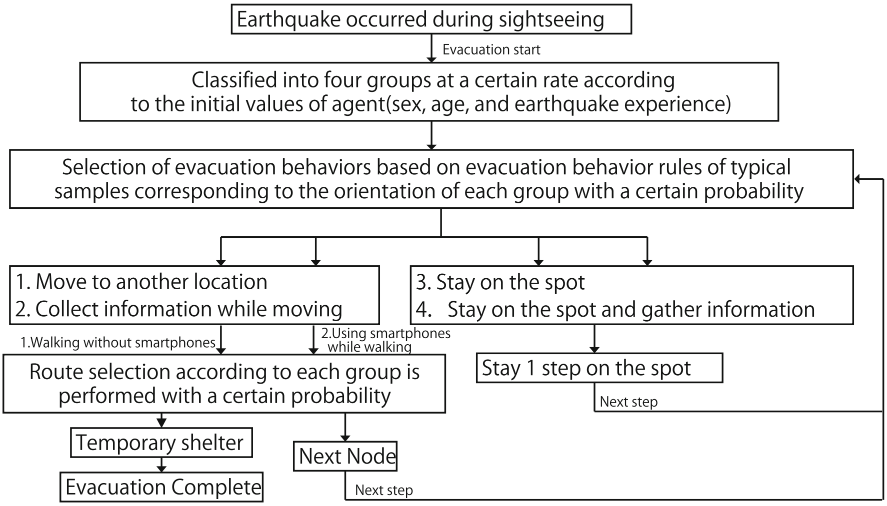


Fig. 14.7 Agent's behavior algorithm

Table 14.8 Simulation case setting

Case	Time from the occurrence of the earthquake to the time when the transportation system recovers	Time from earthquake to power outage, time to radio wave recovery	Instructor's instruction
1	30 min	Yes	Yes
2	Do not recover	Yes	Yes
3	30 min	None	None
4	30 min	0.49	Yes

most prioritized factor in the route selection: the route directed by the authorities and signs. A simulation was conducted five times with the number of agents set to 5000 (composed at ratios shown in Table 14.10); the simulation duration was 3 h, and 1 h after the start of the simulation, an earthquake occurred.

14.5.3 Evacuation Simulation Results and Consideration

The simulation results are shown in Fig. 14.8 and Table 14.11. Figure 14.8 shows the number of agents who completed the evacuation for each case, and Case 2 showed the most efficient evacuation. A likely cause is that with a continued lack of power preventing smartphone use, many agents decided to move from their place as their evacuation behavior. In contrast, Case 4, compared to Case 2, showed that 934 agents had not completed evacuation even after 3600 seconds had passed. A possible cause is that no available public transport resulted in many agents deciding to stay in their place as their evacuation behavior.

Table 14.9 Simulation case setting

Case	Contents
1	In the case that power failure continues, radio waves do not reach and receive no influence of smartphone (route search using a smartphone) (electricity and reception down; evacuation walking speed, 1.5 m/s)
2	The primary case in this study sets to restore traffic, power, and reception in 30 minutes after the earthquake (transportation, does not know if it is moving → moving· electricity, reception, stopped → recovered)
3	A case of transportation such as trains and buses to return is not restored (transportation: I do not know whether it is moving · electricity, reception, stopped → recovered)
4	A case where the sightseeing site is confused by the earthquake and the direction cannot be received. (transportation: I do not know if it is moving → moving,· electricity, reception, stopped → recovered) (· no direction by the instructor)

Table 14.10 Agent configuration

Sex	Male,55.2%; female, 44.8%
Male	20s, 15.3%;30s, 23.6%; 40s, 20.2%; 50s, 15.4%; 60s, 25.5%
Female	20s,18.8%; 30s, 24.9%; 40s, 17.4%; 50s, 16.2%; 60s, 22.7%
Earthquake experience	Earthquake experience, 39.1%; not, 60.9%

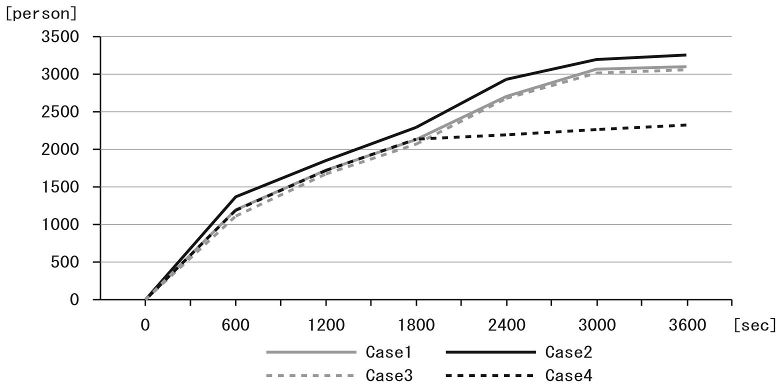


Fig. 14.8 Trends in evacuation number by case

Table 14.11 gives the maximum evacuee density of the route network for each case. Table 14.11 shows few differences among cases (no significant difference at a level of 5%). The reason for this could be that fewer branch paths on the simulation route resulted in no dispersion throughout evacuation routes due to few differences in the route selection.

Table 14.11 Maximum evacuation density by case

Case	Average	SD	Min	Median	Max	*T*-test
1($n = 5$)	1.14	0.84	0.06	0.88	3.03	Combination from Case 1 to Case 4 amounts to combination of six patterns to verify the difference in mean value → 5% N.S
2($n = 5$)	1.06	0.74	0.06	0.85	2.90	
3($n = 5$)	1.11	0.81	0.03	0.88	2.95	
4($n = 5$)	1.12	0.81	0.05	0.92	2.96	

Unit: person/m^2

14.6 Concluding Remarks

As a result, it is possible to conduct an agent modeling technique combined with a sampling survey and develop a tourist evacuation behavior agent model considering information behaviors in an earthquake. Moreover, this study could show an evacuation simulation of Himeji Castle as a case study using the tourist evacuation behavior agent model.

Our future work includes that we will implement more complicated routes to consider route selection further and increase the simulation accuracy.

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Chapter 15
Virtual Grounding for Agent-Based Modeling in Incomplete Data Situation

Shingo Takahashi

Abstract When modeling social systems, grounding of the model with regard to the real-world aspects that are the target for modeling allows for the determination of model parameters, as well as consideration of the consistency between the behavior of the overall system and real data. Hence, grounding is a part of conventional methods for obtaining external validation of a model (Schreiber C, Carley KM (2007) Agent interactions in construct: an empirical validation using calibrated grounding. In Proceedings of the Behavior Representation in Modeling and Simulation Conference (BRIMS)). Real-world grounding is essential to scenario analysis of specific management conditions, and when performing grounding, actual data serve as the connection between the model and the real world.

15.1 Introduction

When modeling social systems, grounding of the model with regard to the real-world aspects that are the target for modeling allows for the determination of model parameters, as well as consideration of the consistency between the behavior of the overall system and real data. Hence, grounding is a part of conventional methods for obtaining external validation of a model (Schreiber and Carley 2007). Real-world grounding is essential to scenario analysis of specific management conditions, and when performing grounding, actual data serve as the connection between the model and the real world.

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Generally speaking, when using simulations as an aid to management, there are a variety of problems concerning the use of data in model validation (Law 2007). In agent-based social simulation (ABSS) research, model validation is confirmed by different methods according to the abstractness of the model (referred to as the "model resolution"). Validation has a close relationship with the goals to be achieved by applying the model (National Research Council 2008). Gilbert (2007) classifies agent-based models into three types according to the validity evaluation: abstract models, middle range models, and facsimile models. Taking the simulation of a cell-type model as an example of an abstract model, an important goal will be to use the simulation (Epstein and Axtell 1996; Schelling 1969) results to make meaningful observations related to theory construction for understanding social systems. The validity of the abstract model will therefore be evaluated depending on basic causal correlations that explain the rules of the overall system and the consistency of these rules with observed events. The middle range model establishes focal points from among complex phenomena, and its primary goal is to analyze the effects of target policies. The validity of the middle range model is evaluated, thereby, according to the simulation results and qualitative consistency between accepted theory and the stylized facts established in the model. Abstract models and middle range models represent not specific social situations, but rather more general ones, and place an emphasis on the discovery of universal social systems. Therefore, even though actual data will be used on occasion for establishing parameters, there are substantial difficulties in evaluating validity through studying the consistency between actual individualized data and the details of agent behavioral models.

The facsimile model, on the other hand, analyzes the utility of specific policies under individualized problem conditions, thus making it an aid in decision-making for management and policy decisions. Identification of agent behavioral models to be included in specific target situations is necessary for effective analysis of specific policies. To that end, actual data must be accommodated in order to calibrate the model and to evaluate its validity. Previous research has shown that normal experiential grounding can be based on simulation results (Harrison et al. 2007).

To date, in the field of social simulation research, there have been few reports on policy analysis that uses a facsimile model including detailed and valid behavioral models, such as that for the H1N1 influenza pandemic (Putro et al. 2008). The main reason for this lack of studies is that most actual data readily available for use in the creation of agent behavioral models are usually inadequate. For example, to determine the parameters for the Tokyo DisneySea (TDS) visitor agent facsimile model presented in this paper, it was necessary to obtain a sufficient quantity of behavioral data related to visitors under a variety of conditions. Not only do visitors display different behavioral characteristics according to individual differences, but even the same person will show different behavior according to factors associated with the day of the visit (e.g., day of week, weather, and time of arrival). Systematically and exhaustively collecting the amount of behavioral data necessary for agent behavioral model identification is no small task.

To make up for deficiencies in behavioral data, even in cases where analysts perform empirical investigations in an attempt to obtain behavioral model data for agent model construction, limitations on the field research can prevent analysts from collecting sufficient data for facsimile model construction. For example, all Tokyo Disney resorts operate under the concept that they are "the place where dreams come true," and as a result, the TDS park manager does not permit data collection within the park on the premise that such activities are not a part of visitors' dreams. This restriction means that detailed data on the behavior of visitors at TDS are unavailable but also that collecting such data directly from park visitors is not possible. Therefore, demonstrating the validity of specific policies under actual conditions has been difficult, and scenario analysis has been limited to assessing the general effectiveness of policies by using a middle range model.

This chapter proposes virtual grounding (VG) as a method for constructing valid facsimile models under conditions where the real-world data essential for behavioral model determination cannot be obtained. The proposed method makes it possible to explicitly describe the effectiveness of policies under specific conditions. As an example application of VG, the construction of an agent model for visitors to TDS is presented. In this example, the overall system behavior and the micro dynamics of individual agents are investigated through simulation results, and the effectiveness of VG is demonstrated through a comparison with actual park conditions.

The main features of VG are that model construction is determined through models for which utility has already been demonstrated and that data are produced through repeated virtual experiments using a web-based questionnaire on decision-making behavior by agents who are the targets of modeling and yet operate within the model. Hence, sufficient data can be obtained for statistical identification of the behavioral model. Moreover, behavioral data are directly related to participant behavior within the model, leading to realistic simulation results.

15.2 Virtual Grounding Method

15.2.1 Modeling Relation in General Grounding

Broadly put, grounding makes possible consideration of the relationship between the real world, a model, and data (Fig. 15.1). The specific functions employed depends on the resolution of the abstract, middle range, or facsimile model used, but in essence a model is constructed through abstraction of the real world, and that model leads to understanding through explanation of real-world phenomena. Grounding of the model with the real world is particularly important when constructing a high-resolution model, such as a facsimile model. Data are normally obtained through real-world sampling. Parameters that determine the construction of the model are estimated from data, and the model generates data that can be interpreted in the real world.

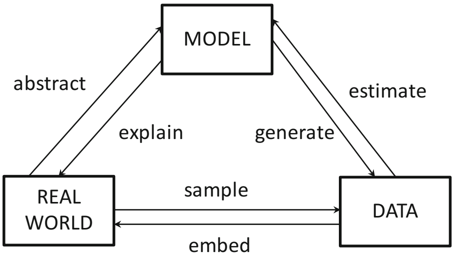

Fig. 15.1 Modeling relation in general grounding

15.2.2 Virtual Grounding

Facsimile models that analyze policies for specific situations are created in line with actual conditions. As presented in this paper, a theme park such as TDS requires determination of the parameters for tens of thousands of agents composed of the behavioral model.

Determination of such parameters from actual data, however, is complex for the following reasons. Firstly, for statistical estimation methods, enough data can rarely be obtained to guarantee sufficient precision. Secondly, even when a certain amount of actual data has been collected, in many cases the dataset will show only behavior within some limited part of a set of constantly changing conditions. Behavioral models require parameter estimations for agent behavior under a variety of conditions, and a model that generates behavior valid for a given dataset will almost certainly not generate valid behavior under different conditions. Thirdly, real data often cannot be obtained for political or organizational reasons. In the case of TDS, to generate an agent behavioral model for attraction selection, utility function selection parameters are needed to be estimated from actual data (past or present) on park visitors' selection behavior. Nonetheless, statistically useful data for this purpose do not exist, and park managers refused to permit collection of new data by, for example, asking park visitors to participate in a questionnaire.

In this paper, the problem of obtaining actual data related to behavioral model grounding for a facsimile model is addressed, and the VG method is proposed for generating virtual data to use in behavioral model identification. VG is effective for situations where it is difficult to obtain actual data from systems targeted for model analysis.

Figure 15.2 shows an overview of the modeling relationships in VG. An existing and accepted behavioral model determines the structure of the behavioral model that is the target of analysis. Real-world data are not used; instead, participants in a questionnaire are used as agent samples and perform virtual behavior within the behavioral model. This virtually generated data (termed "virtual data") are then used to estimate behavioral model parameters.

The difference between VG and standard grounding is that data to be applied to the model formulation are not acquired directly from the target of analysis but rather virtually generated from the agent sample space.

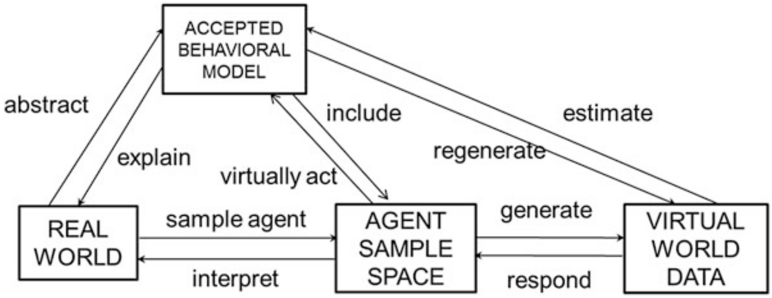

Fig. 15.2 Modeling relation in VG

As the research associated with VG, there have been MAS (multi-agent simulation)/RPG (role-playing game) methodology (Barreteau et al. 2001, 2004; Adamatti et al. 2009) and agent-based participatory simulations (Guyot and Honiden 2006; Nguyen-Duc and Drogoul 2007). These studies also conducted the participatory experiments to gain the agent behavioral data. In particular, agent-based participatory simulations have the advantage to modify a model structure by recoding the behavior. Their purpose, however, is mainly training and education and as a support for negotiation. Thus they do not always have to create a facsimile model as long as the participants achieve the purpose with a middle range model. In fact, they could not provide any estimation method for building a facsimile model. VG can be used to identify statistically the parameters of the facsimile behavioral model to be built.

VG is generally performed according to the following three steps. More detailed description how to apply the steps in an actual situation can be found in the subsequent sections.

Step 1: Model Selection

The target for analysis determines the qualitative features of the agent, and a model for which utility has previously been demonstrated within the domain (an accepted behavioral model) is used to establish the structure of the agent behavioral model. The model should be selected so that its parameters can be determined, in the following steps, by some calculation method for estimating them.

Step 2: Virtual Data Generation

Participants to be modeled as agents "generate" data by performing virtual decision-making and behaviors in virtually created situations. It is vital at this step to gather sufficient samples for identification of model parameters for Step 3 and to have participants make repeated decision-making behaviors under changing conditions by dynamically altering parameters. By doing so, data can be collected from similar-type agents under different conditions that are conceivable within the model; thus, the required parameters can be estimated.

To construct a valid behavioral model, carefully selecting the participant sample space is crucial. It is necessary not only to collect a sufficient number of samples but also to find participants with attributes that represent the distribution found in reality.

Step 3: Determination of Model Parameters
Data generated in Step 2 are used to parameterize the behavioral model. The validity of the identification method relies on the behavioral model composition. For example, for logit models frequently used in marketing science, segmentation clustering must be performed, and parameter estimations are derived by the maximum likelihood method.

15.3 Applying VG Method to Theme Park Problem

Here, VG is applied to the theme park problem (Kawamura et al. 2003), a typical problem for which ABSS is accepted as valid. In the theme park problem, visitors are presented with attraction wait times, and the effects on congestion reduction are analyzed. The utility of such wait time display policies has been previously demonstrated (Kataoka et al. 2004; Tone and Kohara 2007). Previous research used middle range models as behavioral models for parks and agents but did not take into consideration the specific conditions of individual theme parks. This lack of customization of the problem makes it difficult for theme park managers to verify the effectiveness of policies under conditions particular to the parks that they manage. Here, TDS is taken as a case theme park for application of VG in constructing a theme park briefly discussed in Sect. 15.3.1 and a visitor agent facsimile model discussed in Sect. 15.3.2.

15.3.1 Theme Park Model

The theme park model is a general representation of common structures in a theme park. The model is composed of four types of structural elements—attractions, events, routes, and entrance gates—each represented as nodes in a network. Links are established between nodes that can be directly traversed by visitor agents.

Parameters for the attractions, routes, and entrance gates were set to closely match the actual park conditions. Values were determined through an interview with a representative of Oriental Land Co., the managing company of TDS, and through information made publicly available, for example, on the TDS website.

15.3.2 Visitor Agent Model

This section describes the construction of a visitor agent model according to the three VG steps described in Sect. 15.2. Firstly, an attraction selection behavioral model is formulated, based on an accepted model of consumer purchases from the marketing science field (Step 1). Next, the selected model is used to build a model that dynamically varies its parameters according to park conditions, and the participants perform virtual behavior within the model environment (Step 2). Significantly, the method takes into consideration effects of various park conditions on agent behavior and is one of the most pertinent features of VG. To reflect these issues, attributes affecting agent behavioral differences, according to conditions such as day of week (weekday versus weekend or holiday) and accompanying agents (family versus friend), must be accounted for. Therefore, the model parameters are dynamically varied through a web interface, and the participants repeatedly perform decision-making under each condition. The virtual dataset obtained through the repeated decision-making performed in Step 2 is then used to determine visitor agent behavioral model parameters through statistical estimation (Step 3).

Step 1: Model Formulation

In Step 1 the visitor agent model is selected by using a model determined to be appropriate through previous research. Visitors usually have multiple preferred attractions upon arrival on a given day and will select attractions to ride on the basis of their current location within the park and attraction wait times. This behavior closely parallels consumer purchasing behavior, where consumers select from multiple recollected products after narrowing down the selection group and make a selection based on a calculation of product utility (Manski 1977; Shocker et al. 1991) (Fig. 15.3). The present research thus takes advantage of this similarity in visitor and consumer purchasing behavior to create a visitor agent model based on a consumer purchasing behavioral model for which effectiveness has already been demonstrated in marketing science.

Agent's Internal Model

A visitor agent, v_h, contains within its internal model both objective and subjective information related to the selection of attractions a_i ($i = 1,2,\ldots,26$:the number of the attractions of TDS) and performs decision-making in reference to such information. When each agent arrives at the park, it evokes a list of attractions and events e_k ($i = 1,2,\ldots,9$:the number of the events of TDS) that the agent wants to enjoy, represented as an attractions evoked set $at\_evoked\_set_h$ and an events evoked set $ev\_evoked\_set_h$. Agents choose attractions to actually ride from the evoked attraction list based on wait times and FastPass ticket availability. Chosen attractions are represented as $at\_choice\_set_h$. Whether the wait time for a_i is read from the attraction's information board is determined according to the parameter $awareness_{hi} \in \{0,1\}$ ($i = 1,2,\ldots,26$). Furthermore, each agent contains the following parameter group as an internal model: congestion information, $congestion\_info_{hi} \in N (i = 1,2,\ldots,26)$ provided via information boards about attraction a_i; a decision-making threshold related to congestion, $threshold_{hi} \in N (i = 1,2,\ldots,26)$; information board reference probability, $IB\_watch\_rate_h \in [0,1]$; a set of attractions for which the agent is aware of FastPass ticket availability, $FASTPASS\_aware_h$; a set of attractions for which FastPass tickets are possessed, $FASTPASS\_possess_h$; a set of FastPass times for each attraction, $FASTPASS\_time_{hi} \in N$ ($i = 1,2,\ldots,26$); a list of event starting times for each e_k, $entertainment\_time_{hk} \in N$ ($k = 1,2,\ldots,9$); fixed interest level for a_i, α_{hi} ($i = 1,2,\ldots,26$); and distance and congestion utility weightings for individual agents, $\beta 1_h$ and $\beta 2_h$, respectively.

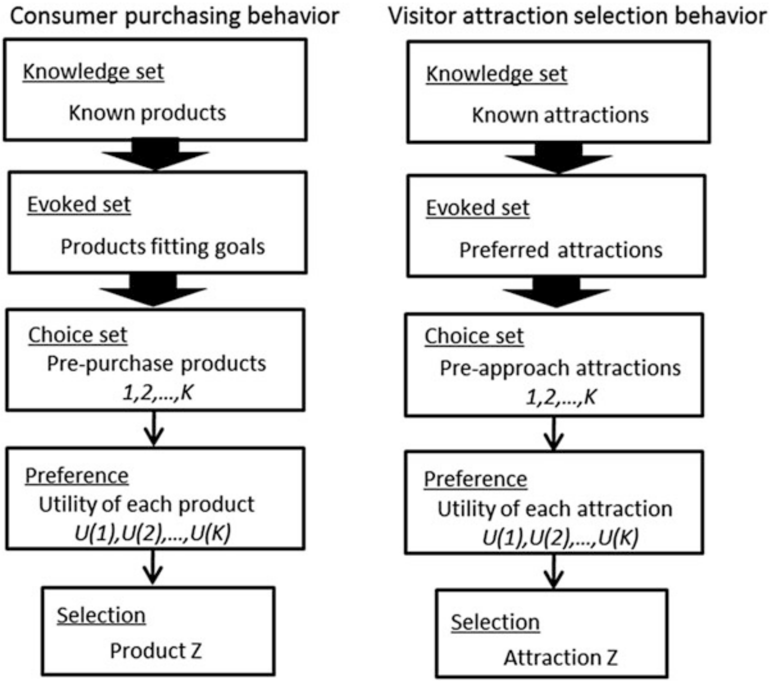

Fig. 15.3 Comparison of attraction selection behavior and consumer purchasing behavioral models

Upon creation, agents are assigned $at\_evoked\_set_h$ and $ev\_evoked\_set_h$, in addition to $threshold_{hi}$, $congestion\_info_{hi}$, a fixed α_{hi} for a_i, and $\beta 1_h$ and $\beta 2_h$. These parameters are determined in VG Step 3.

Behavioral Model

The agent decision-making process is modeled as follows. Fig. 15.4 shows an overview of the process.

(a) *Obtaining and updating congestion information*

When located at r_l for which an information board exists ($Information\_board_l = 1$), v_h obtains congestion information according to $IB\_watch\_rate_h$. Where no information board exists on r_l, congestion information is obtained according to $at\_congestion\_rate_l$ for the adjacent attraction to r_l. At that time, $awareness_{hi}$ representing knowledge of the congestion information for a_i is set equal to 1 if congestion information was obtained for that attraction and 0 if otherwise.

Next, updating of $congestion\_info_{hi}$ for attractions within $at\_evoked\_set_h$ for which $awareness_{hi} = 0$ is performed by using congestion information that is presented on other information boards. For cases where there is a mismatch

```
/* Decision-Making Process */
integer list array at_choice_set;// agent's internal model
boolean move_judgement;//whether the agent is movement toward a destination
or not.
boolean arrival_judgement;//whether the agent stays in a destination or not.
boolean congestion_information_judgement; //whether the agent found out new
information about attraction congestion or not.
boolean fp_judgement;//whether the agent have a fast pass ticket or not.

decision-making process()
          congestion_information_judgement = Obtaining_and_updating_congestion
          _information…(a)
          IF arrival_judgement == true THEN
                    fp_ judgement = receives_a_Fast_Pass…(e)
                    IF fp_judgement == true THEN

                          arrival_judgement = stay_destination() // return false, if
the agent finishes to ride the attraction.
                    ENDIF
          ELSEIF  congestion_information_judgement == false and
move_judgement == true THEN
                    move_to_destination() // the agent move to his/her destination
          ELSEIF  congestion_information_judgement == false and
at_choice_set.length == 0 THEN
                    schedule confirmation and random walk…(f)
          ELSE
                    Creation_of_the_selection_group()…(b)
                    IF at_choice_set.length == 0 THEN
                              move_judgement = confirming_a_schedule…(f)
                              IF   move_judgement == true THEN
                                        move_to_destination()
                              ENDIF
                    ELSE
                              attraction_selection…(c)
                              move_to_destination()
                    ENDIF
          arrival_judgement = judge_arrival()// return true, if the agent arrive s at a
destination
          ENDIF
STOP
```

Fig. 15.4 Agent decision-making process between the time indicated on information boards and the currently held congestion information ($wt_{li} \neq congestion\_info_{hi}$), $congestion\_info_{hi}$ is updated according to

$$congestion\_info_{hi} = congestion\_info_{hi} \times \lambda_h, \tag{15.1}$$

where $\lambda_h = \frac{\sum_i \lambda_{hi}}{\sum_i awareness_{hi}} \left(\sum_i awareness_{hi} \neq 0\right)$,

$$\lambda_{hi} = \begin{cases} \frac{wt_{li}}{congestion\_info_{hi}} & if \quad wt_{li} \neq congestion\_info_{hi} \\ 0 & otherwise \end{cases}.$$

(b) *Creation of the selection group*

To select attractions that will be actually ridden, $at\_choice\_set_h$ is created by narrowing down $at\_evoked\_set_h$ according to known park conditions.

An attraction a_i belonging to $at\_evoked\_set_h$ is added to $at\_choice\_set_h$ when all of the following conditions are met:

1. For each attraction for which the agent possesses a FastPass ticket, $a_j \in FASTPASS\_possess_h$ $(j \neq i)$, evaluation as to whether a_i can be ridden without exceeding the FastPass usage time is performed from

$FASTPASS\_time_{hk} \geq congestion\_\text{info}_{hi} + st_i + at\_time_{li} + en\_time_{ik}$.Here, $FASTPASS\_time_{hj}$ is the FastPass scheduled time; $congestion\_info_{hi}$ is the congestion information for a_i; st_i is the ride duration; at_time_{li} is the time required to travel from current location, l, to a_i; and at_time_{li} is the time required to travel from a_i to a_j for which the FastPass ticket is possessed.

Agents also evaluate whether there is enough time to view an event after riding an attraction. For each event $e_k \in ev\_evoked\_set_h (k = 1,2, \ldots ,9)$:
$entertainment\_time_{hk} \geq congestion\_\text{info}_{hi} + st_i + at\_time_{li} + en\_time_{ik}$.

2. When agents know that a_i issues FastPass tickets ($a_i \in FASTPASS\_aware_h$) and the agent is not in a time period when FastPass tickets cannot be issued ($FASTPASS\_blank_h$=0), or alternatively, agents do not know that a_i issues FastPass tickets ($a_i \notin FASTPASS\_aware_h$) or $threshold_{hi} \geq congestion\_info_{hi}$.

(c) *Attraction selection*

Next, the utility value of each attraction in $at\_choice\_set_h$, based on $congestion\_info_{hi}$ and travel time from r_l to a_i, is calculated by agents using:

$$U(i) = \alpha_{hi} + \beta 1_h \cdot at\_time_{li} + \beta 2_h \cdot (1 - \delta_i) \cdot congestion\_info_{hi}, \tag{15.2}$$

where

$$\delta_i = \begin{cases} 1 \; if a_i \in FASTPASSAt \\ 0 \quad otherwise. \end{cases}.$$

The agents' selection of and movement to attractions are stochastically generated by a multivariate logit model:

$$p(i) = \frac{\exp U(i)}{\sum \exp U(n)}, a_n \in at\_choice\_set_h. \tag{15.3}$$

(d) *Riding the attraction*

Attraction selections are performed upon each transfer to a route. After arriving, the agent will ride the attraction if Wt_{li} is less than $threshold_{hi}$.

(e) *Receives_a_Fast_Pass*

If the wait time is greater than the threshold and the attraction issues FastPass tickets ($a_i \in FASTPASS\_At$), then the agent receives a FastPass.

(f) *Schedule confirmation and random walk*

When the attraction choice set is empty ($at\_choice\_set_h = \{\}$), the agent does not wish to ride an attraction and will wander randomly through the park until a scheduled FastPass or event time is reached or until some change in the park conditions is recognized. A route contained within $adjacent\_route_i$ for current route r_l is randomly selected, and the agent moves to the selected route. After the move, $threshold_{hi} = threshold_{hi} + 1$ and $explore\_time_h = explore\_time_h + 1$. The $threshold_{hi}$ parameter is reset to its original value each time an attraction is ridden or an event is watched.

Step 2: Virtual Data Generation

In Step 2, data are generated to identify the model parameter values. As described in Sect. 15.2, VG does not determine parameter values from existing data as in traditional methods but instead generates virtual data according to the behavioral model constructed in Step 1.

To generate virtual data, we chose sample participants that had previously visited TDS and used an online questionnaire to have the participants perform decision-making behaviors in the constructed model under a variety of dynamically changing conditions. The sample included 1500 participants—enough to produce statistically valid parameter estimates—from an age distribution similar to that of previous TDS visitors. Questionnaire participants were remunerated, as an incentive to provide accurate responses. The following describes the main methods used for determining each model parameter.

Evoked Set Identification

Following the model, each participant selects the events to watch and attractions to ride that most interested them from a list of all TDS attractions. These data were used to determine $at\_evoked\_set_h$ and $ev\_evoked\_set_h$.

Threshold and Congestion Information Identification
For each attraction in the evoked set, participants gave their anticipated wait times and the maximum time that they would be willing to wait in line. The answers were used to establish how the choice sets were narrowed down from the evoked sets.

Utility Function Identification
By using a map representing TDS attractions and routes, attractions from the evoked set and attraction waiting lists were randomly displayed. In order that participants would have a feeling of reality, present times, FastPass possession information, and FastPass usage times were also presented as additional information. From this information, participants virtually performed attraction selection while at the same time viewing actual theme park maps. Each time an attraction was selected, the presented information was dynamically altered. Decision-making behaviors were studied five times for each sample. Data obtained in this manner were then used to resolve the fixed interest level, α_{hi}, for attractions a_i, and the distance and congestion weights, $\beta 1_h$ and $\beta 2_h$, in Eq. (15.2).

Step 3: Estimation of Model Parameters
Step 3 estimates each of the parameters comprising the model. First, the 1500 samples, having an age distribution,[1] were segmented according to the attractions in the evoke lists. To do the segmentation, the samples were enumerated using Type III quantification, based on those attractions identified as possible for selection in Step 2.

Second, clustering was performed for those sample scores with cumulative contribution ratios of at least 60%, allowing for classification into three daytime segments and four evening (after 6:00 pm) segments.

Next, by the maximum likelihood method, the attraction selection decision-making data obtained in Step 2 were used to estimate the values of α_{hi} for a_i and β_{1h} and β_{2h}.

Finally, the data obtained in Step 2 were used to establish visitor agent generation rates for each segment, $threshold_{hi}$, and the initialization values for $congestion\_info_{hi}$. The simulation presented in Sect. 15.4 is performed by using steps of 1 min, so that steps 1 through 540 performed in each trial represent the segments from 10:00 am to 6:00 pm, and steps 541 and beyond represent the evening segments after 6:00 pm.

[1]Before conducting the main questionnaire survey for VG, we conducted a brief screening questionnaire. First we gained the rates of people having experience of visiting TDS in different ages, which are 18–19, 20–29, 30–39, 40–49, and 50–59. Then we multiply the rate by the number of Japanese population in each age. As a result, we identified the age distribution of the sample participants.

15.4 Theme Park Simulation

Results from running the theme park simulation using the identified parameters are now shown. The example simulation used here is for a typical weekday in August during summer vacation. We verified the effectiveness of the proposed model through comparison between the congestion information in the results of this simulation and those of previous research (Tone and Kohara 2007) and actual TDS data. Moreover, we investigated the actual micro dynamics of an individual agent behavior.

The simulation was performed with actual TDS data as the basis for visitor agent park entrances.

Figure 15.5 shows the average wait times for attractions issuing FastPass tickets and for other attractions as per a simulation using the proposed model.

Actual data on congestion at TDS for an August weekday during summer vacation indicate that congestion became concentrated at the most popular attractions (those issuing FastPass tickets), with other attractions having wait times of approximately 5–20 min. Wait times decreased at times when parade events occur (at steps 180, 420, and 660). The simulation results shown in Fig. 15.5 appear to recreate the actual conditions observed at TDS.

Figure 15.6 describes the peak waiting times for each attraction, comparing the results of the proposed simulation with that of the simulation described by Tone and Kohara (2007) and with actual TDS data from August 5, 2011. For comparison with the simulation, we selected TDS data from a date when there were a similar number of park visitors as simulated visitor agents. Not all attractions are listed, owing to the limited availability of actual data (in itself an indicator of the necessity for the proposed VG model).

We see from Fig. 15.6 that a simulation using the middle range model from previous research indicates extreme waiting times for attractions issuing FastPass

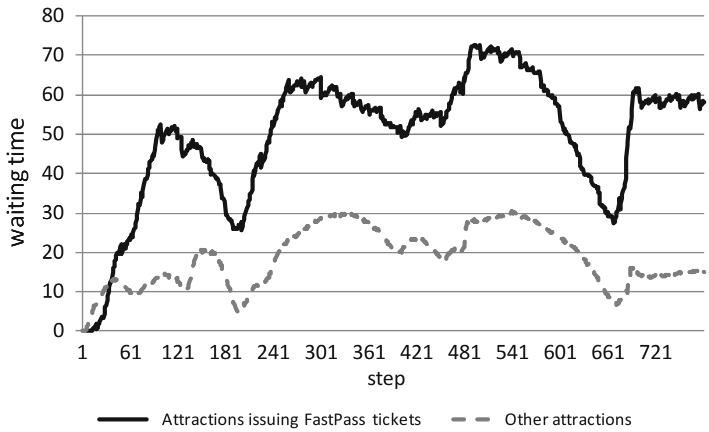

Fig. 15.5 Average attraction wait times

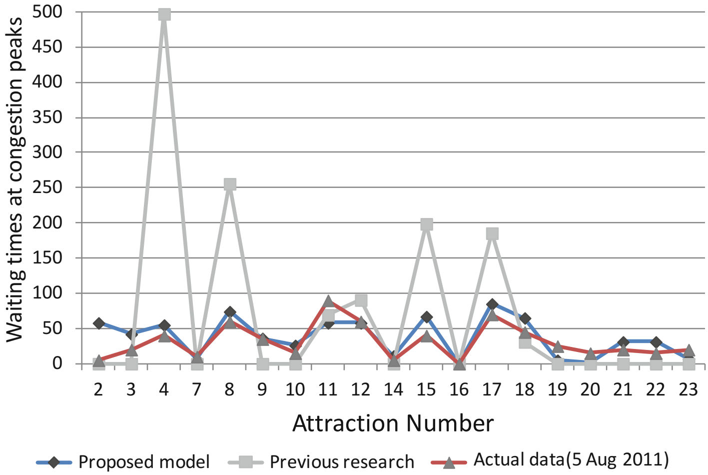

Fig. 15.6 Waiting times at congestion peaks

tickets (attractions 4, 8, 15, and 17), whereas wait times for other attractions are nearly zero—a significant deviation from actual data. In addition, the graph indicates that the simulated waiting time results by the proposed model are close to the actual times for all attractions.

Previous ABSS research has performed model parameter determination after calibration designed to fit macroscale data, such as market share and sales, or stylized facts. The proposed method, however, uses VG to determine parameters without conducting the calibration. Nonetheless, the model produces simulation results close to actual attraction waiting times, demonstrating the utility of VG.

As has been pointed out recently with regard to ABSS research (National Research Council 2008), the utility of a model cannot be fully demonstrated through adjustment of overall simulation behavior to agree with actual data. Model utility should be verified in terms of whether the decision-makers could interpret the simulation results as their situations in order to perform scenario analysis with specific policies. Specific scenario analyses are not addressed here because they are beyond the scope of this paper. However, the ability to interpret agent behavior as that of actual park visitors would indicate its value in performing scenario analysis. To verify the interpretability of the behavior of individual agents, therefore, we investigated the micro dynamics of individual agent behavior.

15.5 Conclusion

We proposed "virtual grounding" as a grounding method for constructing valid facsimile models where real data for behavioral model parameter identification are not available. This method makes it possible to specifically demonstrate the validity of policies under varying conditions through the use of models tuned to those conditions. As an application example, we used an accepted behavior selection model from marketing science to construct an agent model for visitors to TDS, extracting samples from an agent sample space composed of 1500 participants. Each participant used an online questionnaire to perform virtual behavior within the selection model under dynamically changing environmental settings, allowing for statistical estimation of behavioral model parameters. A simulation was performed using the behavioral model, and the results were used to examine overall system behavior, as well as the micro dynamics of an individual agent. The utility of VG was demonstrated through comparison of the results with actual park situations.

The park and behavioral models outlined in this paper are specific to TDS and cannot be directly applied to other situations. Nonetheless, following the method for model construction allows for easy creation of a model for another amusement park with similar features. In that sense, the presented park and behavioral models retain general versatility.

Because our objective here was to demonstrate the VG method, we have not discussed the analysis of specific policies in depth. However, it is considered a straightforward extension of the model to perform scenario analysis on the effectiveness of policies related to lessening congestion in actual park circumstances. Previously, analysis for cases in which data acquisition is difficult was limited to the use of middle range models; conversely, the VG method as presented here expands the possibility of employing facsimile models that can depict individual circumstances, which would have been difficult in the past.

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Chapter 16
Analysis of Problem-Solving Processes

Toru B. Takahashi

Abstract Currently, although artificial intelligence solves many problems, creative problem-solving is an important task that has to be performed by human. However, this is not an easy task. Therefore, we propose a problem-solving support agent that interactively supports human problem-solving activities. Prior to the development of the problem-solving support agent, we organized the problem-solving process and researched the types of mistakes involved in the process. The result of this research clarified the nature of likely human errors and types of functions required to be performed by the problem-solving support agent.

16.1 Introduction

In recent years, artificial intelligence (AI) has been used for solving many problems. In chess, AI has won against professional players, and trials are being conducted to utilize AI for automatically driving automobiles. In response to these developments, there are predictions that AI will replace humans in their roles in future (Frey and Osborne 2017).

By contrast, human skills are still required in creative problem-solving. It is difficult for AI alone to first determine the problem and then find an approach to solve it. Therefore, in the future, the skills to creatively solve problems will be increasingly required. The problem-solving skill is included in the *Assessment and Teaching of 21st Century Skills*, which proposed the skills that will be valued in the twenty-first century (Griffin et al. 2012).

However, problem-solving is difficult even for humans. Logical thinking and critical thinking are required during problem-solving, but they are not easy to acquire. Moreover, although tools such as issue tree and 5 Whys that are useful for problems solving are available, they are difficult to master.

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Table 16.1 Problem-solving process

	Mint (1996)	Bransford and Stein (1993)	Dewey (1997)
(1) Ascertain the objective and current situation and grasp the general outline of the problem	1. What is the problem?	1. Identifying problems and opportunities	Face the problem
(2) Analyze the problem and discover what needs to be solved	2. Where does it lie?	2. Define goal	Locate where the problem is and define it
	3. Why does it exist?		
(3) Plan a solution of the problem	4. What could we do about it?	3. Explore possible strategies	Propose possible solutions of the problem and examine them
	5. What should we do about it?	4. Anticipate outcomes and act	
(4) Implement the solution and evaluate it		5. Look and learn	Reflect on the result

For example, in chess, a tournament where a mixed team of humans and computer competed was organized. Even though professional players participated in this tournament, it was the mixed team of amateur players and computer that won. This result suggests that if humans and computers can build a good collaborative relationship, it would lead to significant outcomes.

In other words, it can be inferred that in the field of problem-solving, the quality of problem-solving will increase if an appropriate collaboration can be established between humans and computers. Therefore, we propose a problem-solving support agent. This problem-solving support agent does not directly solve problems. Instead, it supports the thought process of humans during problem-solving, alerts them with the possible mistakes made during problem-solving, or prevents the mistakes.

Therefore, in this chapter, we first clarify the nature of the problem-solving process. Next, we research the potential mistakes in this process. Finally, we will describe the specifications that are suitable for the problem-solving support agent (Table 16.1).

16.2 Problem-Solving Process

We define the proposed problem-solving model based on previously proposed models. Many models and methods of problem-solving process have been proposed not only in the field of pedagogy but also in those of cognitive psychology and business (Bransford 1993; Dewey 1997; Mint 1996; Newell and Simon 1961). Based on these, the problem-solving model is defined as follows:

(1) Ascertain the objective and current situation and grasp the general outline of the problem.
(2) Analyze the problem and discover what needs to be solved.
(3) Plan a solution of the problem.
(4) Implement the solution and evaluate it.

The first stage is to ascertain the objective and current situation and grasp the general outline of the problem. Dewey (1997), from the field of pedagogy, says that one must start from recognizing the problem. Mint (1996), from the field of business, describes the first stage of problem-solving as "What is the problem?—Picture the difference between the current result and the desired result." The IDEAL model proposed by Bransford and Stein (1993), from the field of cognitive psychology, defined the first two stages as follows: "Identifying problems and opportunities" and "Defining a goal." This recognizes the potentials for improvement and suggests the necessity for setting a goal toward it instead of regarding the current situation as given. Newell and Simon (1961) also regard the problem to be the gap between the goal and the current situation. As can be seen in these examples, it is necessary to verify the goal and current situation and recognize the existence of the problem as the first stage of problem-solving.

Next stage is to analyze the problem and discover what needs to be solved. Mint suggests that after "Finding out what is the problem," the next steps include answering the following questions: "Where is the problem?—Picture the factors that constitute the current situation that is causing the problem" and "Why there is a problem?—Analyze each factor and clarify why they are causing the problem." This suggests the necessity for clarifying the cause of the problem by delving into it after grasping the outline of the problem. The IDEAL model of Bransford also points out the importance of discovering the problem, even though there are overlaps with the aforementioned "Identifying problems and opportunities" and "Define a goal." Dewey defines locating the problem as the next stage. Moreover, tools such as an issue tree that hierarchically analyzes the problem are proposed at this stage. As one can see, it is necessary to analyze within the framework of the problem and decide what the problem is.

The next stage is to plan a solution of the problem. Mint reports that after determining the problem to be solved, the following steps are required: "What can you do about the problem?—Write down a plan for a change that can achieve the desired result logically and systematically" and "What should be done about the problem?—Integrate the change plans to achieve the most satisfactory result and build a new structure." This suggests the necessity of a logical formation of the solution plan to achieve a good result in relation to the defined problem. Dewey also discusses the necessity of deciding on a suitable solution plan for the problem. Bransford sets a stage called "Anticipate outcomes and act" in addition to "Explore possible strategies." This means one must predict the possible result of the solution plan instead of immediately implementing it. As one can see, at this stage, it is important to logically plan the solution to solve the problem.

Finally, the last stage is to implement the solution and evaluate it. Bransford calls this stage "Look and learn." This means it is important to observe the result of implementing the solution and learn from it. Dewey also says it is important to both experience the process of implementing the solution plan and reflect upon it. Evaluation is significant for the success or failure of the solution and by learning from it, also for the PDCA cycle of determining the points to be improved for the next implementation.

As discussed above, it is clear that the process of problem-solving is conducted in four stages. The next section will explain the possible mistakes that could arise when engaging with problem-solving based on these four stages.

16.3 Research on Mistakes During Problem-Solving

In this section, the mistakes that a person may make during the problem-solving process are shown based on the experimental result. From this result, the type of support that a problem-solving support agent should provide is examined.

16.3.1 Experiment 1: Mistake During the Problem-Solving Process

In this experiment, a classroom lecture was held for university students, and they were asked to reflect on the process of problem-solving using their everyday problems as its subject. We will show the mistakes that were made during this process.

16.3.2 Experiment Condition/Method

The experiment included 76 participants. Each participant thought of four themes and filled in a problem-solving worksheet. They were given 6 days to complete this task.

The problem-solving worksheet included six sections to be filled, namely, "goal," "current situation," "problem," "solution," "problem analysis," and "Basis for Solution." They were determined following the aforementioned problem-solving process to its third stage.

"Goal" and "current situation" are set based on the aforementioned (1) ascertain the objective and current situation and grasp the general outline of the problem. Here the criterion of evaluation is whether the goal is clearly defined. However, regarding "current situation," because the participants decide the problem themes themselves, it is difficult to evaluate whether a participant is correctly assessing the current situation.

Table 16.2 Number of mistakes during the problem-solving observed in Experiment 1

Type of mistake	Number of the worksheet that made the mistake
(1-1) Goal is not clear	6
(1-2) Implementation of the solution is used as the goal	7
(2-1) The problem is not analyzed	6
(2-2) The problem is not sufficiently examined	See Fig. 16.1
(3-1) The correspondence between the discovered problem and its solution is partially disconnected	73
(3-2) The solution contradicts the analysis of the discovered problem	47

"Problem" and "problem analysis" are based on (2) analyze the problem and discover what needs to be solved. Because only the summary was written in "problem," it was difficult to determine through what process the participants arrived at the problem. Therefore, they were also asked to describe this process in "problem analysis." The criterion of evaluation here is whether the participant is logically analyzing the problem.

"Solution" and "Basis for Solution" are based on (3) plan a solution of the problem. If only the summary of the solution plan is described, the thought process behind it is difficult to understand. Therefore, we required the basis for it to be written in "Basis for Solution." The criterion for the evaluation here is whether the solution plan is based on the analyzed problem.

16.3.3 Experimental Result

Table 16.2 shows the types of mistakes the participants encountered during the problem-solving process. Furthermore, Fig. 16.1 shows the number of problems that were deeply understood related to "2-2: The problem is not sufficiently understood," which will be discussed later.

The mistakes made at the stage of (1) ascertain the objective and current situation and grasp the general outline of the problem originate from failing to properly recognize the outline of the problem. When examining the mistakes made during the experiment, there were participants whose (1-1) goals were not clear. Moreover, there were participants who thought of the solution before clearly defining the goal, and as a result (1-3) implementation of the solution became the goal. If one makes this mistake, there is a danger that he/she overlooks other possible solutions for the problem.

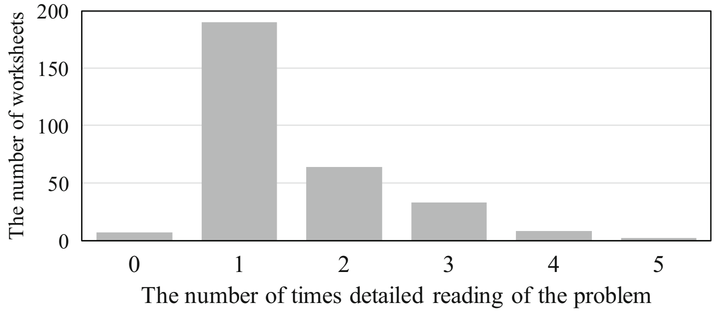

Fig. 16.1 The number of times detailed reading of the problem was conducted

Goal
I would like to socialize with people from other departments, other years, and other schools.
I have no problem with the current situation.

Fig. 16.2 An example of mistake (1-1) goal is not clear

Goal
Earn enough money to at least pay for the living cost by myself.

Fig. 16.3 An example of mistake (1-2) implementation of the solution is used as the goal

Figures 16.2 and 16.3 show the examples of these mistakes. The example in Fig. 16.2 shows that the participant is satisfied with the current situation while describing the problem, thereby making it unclear what he/she really wants. The example in Fig. 16.3 sets the solution "earning money" as the goal. In this way of thinking, it is impossible to consider the reduction of expenses aside from increasing the earning in the later process.

The mistakes made in "(2) Analyze the problem and discover what needs to be solved" originate from the failure to properly analyze within the problem outline set in (1). Even though the analysis must be conducted within the outline of the problem, there were participants who (2-1) failed to analyze the target problem. This includes cases such as diverging from the outline of the problem being faced while analyzing or conducting the analysis based on generalization. Furthermore, even though it was necessary to analyze the problem in depth and locate its cause, mistake in (2-2) understanding the problem simplistically without examining it in depth was made.

Figure 16.4 shows an example of the (2-1) mistake. This participant only made a generalized analysis of the problem that he does not have a girlfriend. Because it cannot be ascertained that the discussed problem applies to him, there is a possibility that proposing a solution to this problem would not be effective. Regarding the (2-2) mistake, Fig. 16.5 shows an example of how to properly examine a problem in

Problem
I do not have a girlfriend.
Problem Analysis
To be popular among girls, it is necessary to be good-looking.
It is common that one is not popular among girls because of one's personality.
It is also common that a boy cannot find a girlfriend because girls have unrealistically high expectations.

Fig. 16.4 An example of mistake (2-1) the problem is not analyzed

Problem
I am often late for a short amount of time.
Problem Analysis
I am often late for a short amount of time.
Because I often miss my train.
Because I often realize I am forgetting something just before I leave home.
Because I am not preparing properly.
Because I do not prepare the day before.

Fig. 16.5 An example of a problem being examined in depth four times in response to the mistake (2-2) the problem is not sufficiently examined

Problem
I find it difficult to get up in the morning.
Problem Analysis
I go to bed too late.

Fig. 16.6 An example of a problem being examined only from one perspective in response to the mistake (2-2) the problem is not sufficiently examined

depth; an example of failing to conduct this examination is shown in Fig. 16.6. From Fig. 16.5, one can observe how the problem is examined using the "5 Whys." In Fig. 16.6, the problem is examined only from one angle, and one cannot see why the participant is staying up late in the first place. Therefore, there is a possibility that a proposed solution may not be able to address the undisclosed deeper reason. Despite these problems, Fig. 16.1 shows that most of the participants examined the problem only from one angle.

(3) Among the mistakes made at the stage where one must plan a solution for the problem, there was the discrepancy in the logical relation between the problem and the solution. (3-1) is the mistake of the correspondence between the discovered problem and its solution being partially disconnected. There was also the mistake of (3-2) the solution contradicts the analysis of the discovered problem.

Figures 16.7 and 16.8 show examples of these mistakes. In Fig. 16.7, the participant lists careless mistakes during exams as the problem. However, he/she proposes to deepen his/her understanding of the test subject as the solution without proposing a solution for the carelessness. In Fig. 16.8, the described problem is the lack of motivation for studying. However, the solution proposed for this problem is to study hard. These two contradict each other, and the solution is clearly impossible to implement.

Problem
My grade is unsatisfactory.
Problem Analysis
I understand the test subject but I often make careless mistakes during exams and do not get a good grade.
Solution
Study the parts where I made mistakes more than the others.
Basis of the Solution
I did not study meticulously enough so I will study and understand every detail for the next exam.

Fig. 16.7 An example of mistake (3-1) the correspondence between the discovered problem and its solution is partially disconnected

Problem
I did not study math.
Problem Analysis
I am not good at math → Because I am not good at it, motivating myself to study math is difficult. → I get worse at math.
It is a negative spiral.
Solution
Study math.
Basis for solution
If I study hard and gain confidence in math, I will be able to escape the negative spiral.

Fig. 16.8 An example of mistake (3-2) the solution contradicts the analysis of the discovered problem

16.3.4 Discussion

From the result of the experiment, many mistakes were observed, and it was ascertained that problem-solving is difficult. In particular, the way of thinking about the problem is an issue.

Both mistakes (3-1) and (3-2) can be regarded as the result of neglecting the seriousness of the problem. Even after analyzing the problem in the previous step, the participants planed solutions that were not based on the analysis. In other words, their thinking about the problem is centered on the solution. This can be inferred from the fact that they made the solution the goal.

There is a possibility that one of the causes of this situation is insufficient analysis. This comes from (2-2) the problem is not sufficiently examined. When the problem is not examined in depth, it can be inferred that it is not possible to discover a problem that leads to the solution. Thus, it is difficult to arrive at the solution directly from the problem analysis result. It can be inferred that the participant reached a solution that ignores the problem analysis as a result.

Therefore, it can be predicted that if the participants are taught about issue tree, which is a useful tool for problem analysis, these types of problems will be reduced. Hence, we verified what types of mistake are made while teaching about issue tree.

16.4 Experiment 2: Mistakes During Problem Analysis

The purpose of this experiment is to verify how mistakes change when the participants are taught about the issue tree, which is a problem analysis tool, and what types of new mistakes are generated.

Issue tree is a method to analyze a problem both horizontally and vertically (Fig. 16.9). The horizontal direction addresses the problem from various angles, whereas each angle is analyzed in depth in the vertical direction. In this way, the problem is examined both widely and deeply.

Its basis structure is to deepen vertically by finding the causes of a problem (Fig. 16.9a). There is also a method to first separate the problem into its constitutive factors. In both cases, the problems generated from one problem or its constitutive factors must be mutually exclusive and collectively exhaustive (MECE). Otherwise, it could become a cause for missing the problem.

16.4.1 Experiment Method/Examination

The participants are the same as those in Experiment 1. They were asked to select two of their problems that were addressed in the earlier Experiment 1, analyze them again using an issue tree, and rethink their solutions. Evaluation, as earlier, was conducted on the worksheet and the produced issue trees.

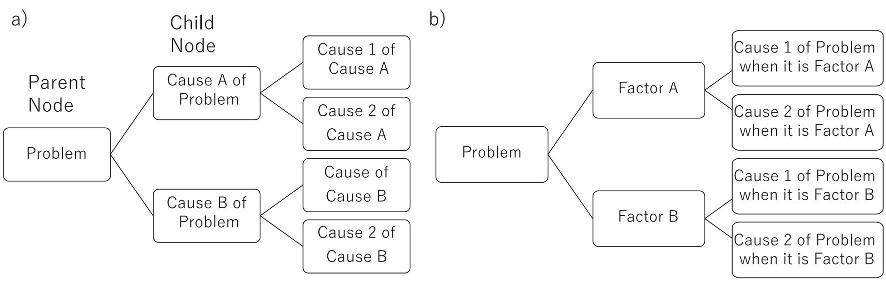

Fig. 16.9 Basic analysis methods of the tree

Table 16.3 Mistakes in problem solutions verified in Experiment 3

Type of mistake	Number of mistakes made
(A) Factors are not properly organized the sentence could be MECE	63
(B) The child node became a mistake	31
(C) The child node is not the category or the cause (except for the solutions)	30
(D) Child node exceeded the outline of the problem	16
(E) The discovered problem and solution are partially not connected	54
(F) There are parts where the discovered problem and solution contradict themselves	22

16.4.2 Experimental Result

Overall, 134 data values were collected. Table 16.3 shows the mistakes observed in the data. However, when a participant shows multiple mistakes in one problem, it is regarded as an overlap.

In this experiment, analysis was conducted by focusing on the problem analysis and solution. (A), (B), (C), and (D) are mistakes related to the issue tree. (E) and (F) are problems that were verified during Experiment 1.

(A) Problem and factors not being organized and there is a possibility that they are not MECE is a mistake that is related to the issue tree. This includes simple omission or repetition as well as leaving the factors that can be organized into a specific category unorganized. This mistake may lead to overlooking of a problem.

Figure 16.10 shows an example of this mistake. It separates the problem of "Lack of talent" into four factors. However, it lists positions such as "second baseman" and "catcher" but does not mention all other positions; thus, it is not MECE. Therefore, it does not conduct a sufficient analysis of other positions. Moreover, "manager" and "team leader" are not positions in a game; hence, they need to be organized in a different category. However, here they are mixed into a category they do not belong to, not making it MECE in another sense.

Next, there was a mistake where (B) the child node became the solution. Here, even though it was in the stage to analyze the problem, the solution to the problem is already proposed. When a solution is proposed too early, there is a possibility that the problem analysis is done insufficiently. This mistake also originates from centering the thinking on the solution.

Figure 16.11 shows an example of the child node becoming the solution. As a response to the problem of "cables are also messy," the solution "tie them with cable binders" is proposed early on. However, if the problem "cables are also messy" was properly analyzed and its concrete factors were examined, it is possible that other solution could have also been examined.

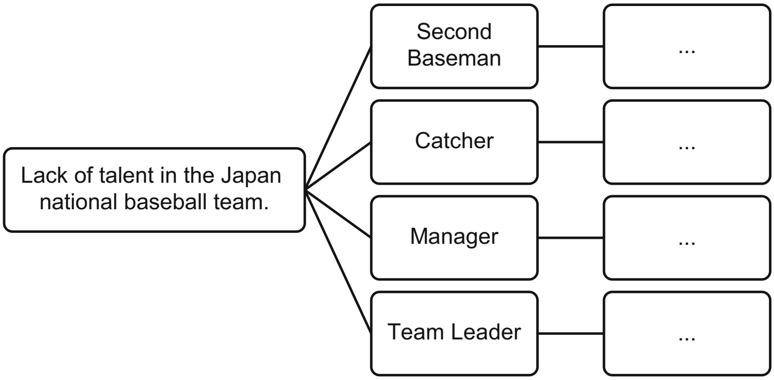

Fig. 16.10 An example of (A) factors are not properly organized and the sentence could be MECE

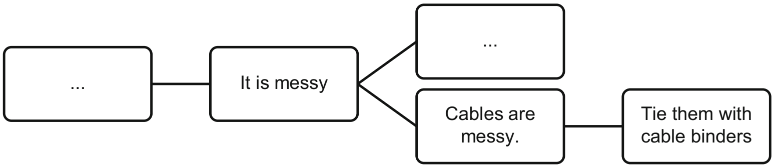

Fig. 16.11 An example of mistake (B) the child node became the solution

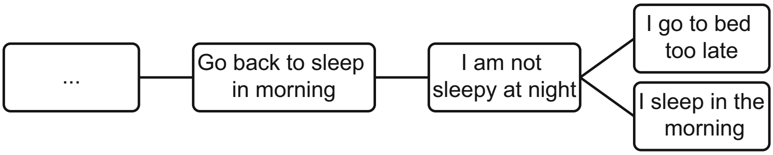

Fig. 16.12 An example of mistake (C) the child node is not the category or the cause (except for the solutions)

Aside from the problems with the solution, there was also (C) the child node is not the category or the cause. It appears that this led not to the cause but also to the result of the problem. Here, the analysis is reversed and will not lead to a solution.

Figure 16.12 shows an example where the result caused by the problem is written in the child node. One can see that the cause of "I go to bed too late" is "I am not sleepy at night," and the cause of that is "I sleep in the morning." Here, it is clear that the analysis is reversed, and therefore, the factors that cause the problem are not examined beyond what is listed at the beginning.

There was also the problem where (D) the child node exceeded the outline of the problem. In the first step of problem-solving, the goal and current situation are confirmed in order to set the area of the problem. However, there are cases where one goes beyond that area while analyzing. A problem discovered that way will not lead to the fulfillment of the goal even when it is solved.

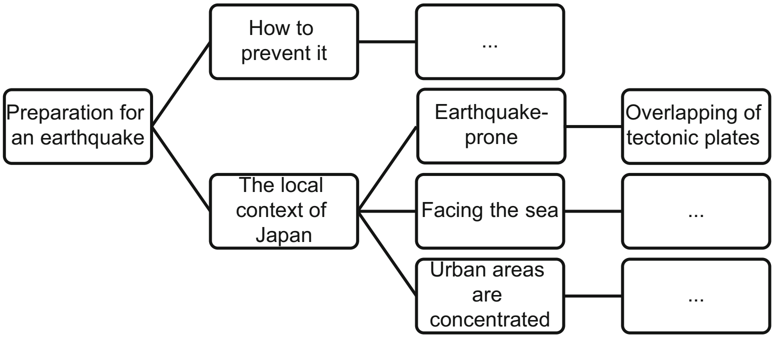

Fig. 16.13 An example of mistake (D) the child node exceeded the outline of the problem

Figure 16.13 shows an example where the outline of the problem is exceeded. Even though the goal was to "Become a person who can respond calmly to any earthquake," the participant lists "overlapping of tectonic plates" during the analysis. This far exceeds the ability of an individual to respond to an earthquake, which is the original goal.

Goal: Become a person who can respond calmly to any earthquake.

(E) The discovered problem and solution are partially not connected, observed in Experiment 1, was also verified in Experiment 2. Moreover, there was no decrease in its number.

Similarly, the mistake (F) there are parts where the discovered problem and solution contradict themselves was observed in Experiment 1. The number of this mistake did not decrease.

16.4.3 Discussion

In Experiment 2, the object was to encourage the participants to devise solutions that address the problems by letting them thoroughly analyze the problems. However, the (E) and (F) mistakes of the relation between problem and solution did not decrease.

It can be inferred that one cause of this situation is the difficulty of problem analysis. In this experiment, the mistake related to MECE was the most common. It is important to think through MECE when using an issue tree. However, this is already a difficult task. Moreover, it is difficult to think back the problem in order to understand the cause, leading to the analysis exceeding the outline or speculating on the result before the analysis is complete.

Moreover, there was the aspect of thinking about the problem being centered on the solution. As seen in Experiment 1, for (E) and (F), the solution was speculated while still constructing the issue tree.

From these results, it is clear that preventing the problem-solver from thinking around the solution and offering support to his/her problem analysis is necessary.

16.5 Specifications of the Problem-Solving Support Agent

16.5.1 What Element Requires Support?

When summarizing the research result, one could see that the following mistakes were made:

(i) Goal is unclear.
(ii) Implementation of the solution is used as the goal.
(iii) The problem is not sufficiently examined.
(iv) The target problem is not properly analyzed during the analysis.
(v) The problem is not analyzed in terms of MECE.
(vi) The analysis becomes the solution during the problem-solving process.
(vii) The problem is not explored in depth during the analysis.
(viii) The outline of the problem is exceeded during the analysis.
(ix) The discovered problem and solution are partially not connected.
(x) The discovered problem and solution contradict each other.

The mistakes made while verifying the goal and the current situation are: (i) goal is unclear and (ii) implementation of the solution is used as the goal. When the goal is unclear, it is impossible to analyze the problem, whereas when the solution is prematurely determined, it prevents examination of other possibilities. Therefore, it is important to guide the problem-solver to a goal that is neither too vague nor too specific.

The mistake made while analyzing the problem to discover the problem to be solved is (iii) the problem is not sufficiently examined. Moreover, during in-depth analysis, it is possible to avoid the following mistakes: (iv) the target problem is not properly analyzed, (v) it is not analyzed in terms of MECE, (vi) it becomes the solution prematurely, (vii) the result is thought about instead of analyzing the problem in depth, or (viii) the solution exceeds the outline of the problem. It is considered to be necessary to use an issue tree in order to encourage the in-depth analysis of the problem. However, there are many mistakes in that process as well. Support is necessary for the problem-solver to structure the problem without using an issue tree.

The mistakes made while planning a solution for the problem are (ix) the discovered problem and solution are partially not connected, and (x) there are contradictions between them. Their cause is considered to be thinking about the problem being centered on determining a solution and not seriously considering the problem analysis result. Therefore, it is necessary to encourage the planning of the solution based on the discovered problem instead of centering the thinking on the solution.

16.5.2 How to Support?

It is difficult for the problem-solving support agent to actively solve problems. Therefore, it is necessary to help the problem-solver to notice mistakes and organize his/her thoughts through dialog. The following are a few examples of such a dialog:

1. When verifying the goal and the current situation in order to grasp the outline of the problem, it is necessary to ascertain through discussion whether the goal is vague or if a concrete solution is prematurely determined. Thus, the problem-solving support agent must ask "Is that call verifiable?" and "What is the purpose of that goal?" The former is a message to encourage checking whether the goal is vague. The latter is to encourage thinking over the set goal in order to arrive at a more wide-ranging goal.
2. When analyzing the problem in order to discover the problem to be solved, it is necessary to guide the problem-solver to structure an issue tree while not making mistakes in its process. It must mainly display a message that says "What is the factor causing this problem" in order to encourage problem analysis. Regarding the horizontal nodes that were listed to let MECE analyze the problem, the following messages must be displayed: "Is there any other possibility?" and "Is there any overlap?" Moreover, to prevent mistakes, messages such as "Is that not a result instead of the cause?" and "Is that not a solution instead of the cause?" must be displayed.

When planning a solution for the problem, it is necessary to lead the problem-solver to think around the problem instead of around the solution. Therefore, thinking based on the analysis result must be encouraged through addressing each problem that was discovered at the end of the issue tree and displaying a message that says "Please think of a solution that can solve this problem." Moreover, it is necessary to encourage the problem-solver to check whether there is no contradiction in the proposed solution compared to other problems.

The above are simple examples of the dialog. In addition, mechanisms to further prevent the mistakes, such as diagrams, are necessary. Furthermore, it is necessary to ask questions that not only prevent mistakes but also help expansion of thinking.

16.6 Conclusion

In this chapter, a problem-solving support agent that solves problems through collaboration with humans was proposed. This agent prevents problem-solvers from making mistakes during the problem-solving process. To propose its basis, we organized the problem-solving process and clarified the likely mistakes made during the process through our research. Furthermore, we demonstrated what types of functions are required from the agent based on the research.

In the future, it is necessary to practically test the problem-solving support agent and examine better relationships between humans and the agent.

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Chapter 17
The Energy Transition Game: Experiences and Ways Forward

Wander Jager, Geeske Scholz, Reńe Mellema, and Setsuya Kurahashi

Abstract We discuss our experiences with the energy transition game (ETG) in Groningen, Tokyo, and Osnabrück, all in educational settings. The ETG is an agent-based game in which roles that can be played are energy companies and political parties. A unique aspect is the inclusion of an artificial population of simulated people. In the ETG the simulated consumers choose an energy provider based on price, safety, and greenness, and they vote for a political party in the government. In this paper, we share the experiences we had with playing ETG with first-year bachelor students at the University of Groningen (The Netherlands), with young professionals from the energy sector at the University of Tsukuba (Japan), and in a mixed seminar for master and bachelor students with diverse interdisciplinary backgrounds at the University of Osnabrück (Germany). The experiences we share with the game suggest that the ETG can be used and developed in different directions: a short introduction of the complexities of the energy transition, courses or projects in which students become codevelopers and try to improve the ETG, or as basis for further extensions and testing of specific hypotheses. We consider a common platform for different versions a sensible next step, including a version control, description of different implementations, and game dynamics.

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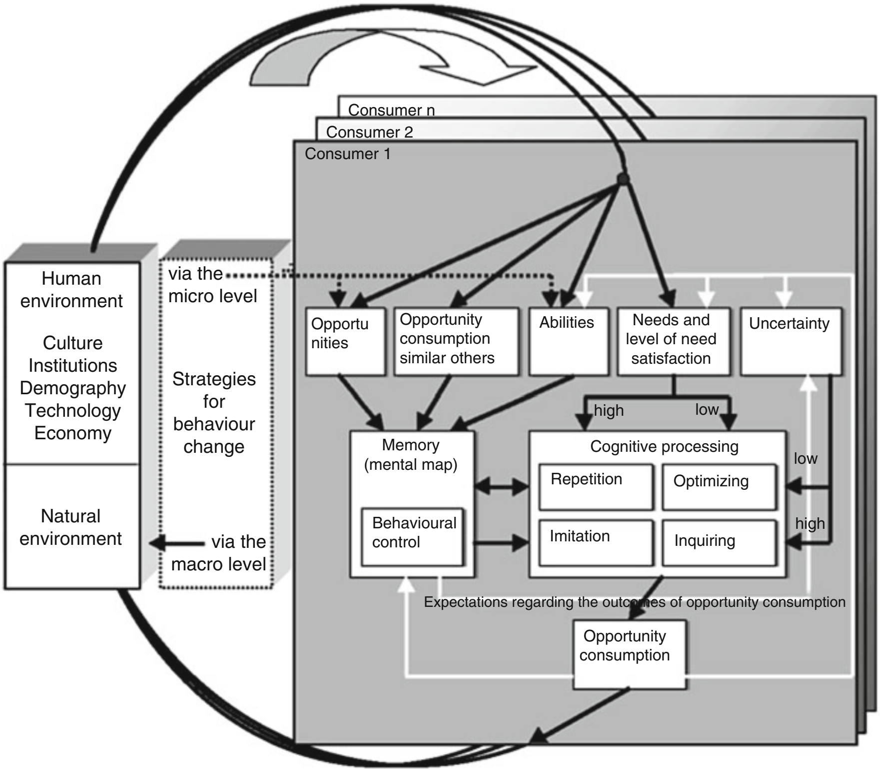

Fig. 17.1 The consumat framework being used for the modeling of the artificial consumers

17.1 Introduction

The energy transition game (ETG) is an agent-based game that allows to take part in achieving an energy transition toward greener power options – or joint failure while trying to achieve it (Jager and van der Vegt 2015). Roles that can be played are energy companies and political parties. A unique aspect is the inclusion of an artificial population of simulated people (Verhagen et al. 2016). As such, the players have to interact with an autonomous heterogeneous population that also interacts with itself. The artificial population used in the ETG is based on the consumat approach (Fig. 17.1) (Jager 2000), which has been developed as a generic framework to guide the development of social simulation models. In the ETG, the simulated consumers choose an energy provider on the basis of price, safety, and greenness, and they vote for a political party in the government. Depending on their satisfaction and uncertainty levels, artificial consumers may behave habitually, optimize, imitate others, or ask others after their experiences with a provider. The players of the ETG can take the role of energy companies or a political party.

The company players make an offering to the consumers by composing a mixture of energy sources. This mixture can be composed of solar, wind, gas, oil, nuclear, coal, or recycling. The raw prices of these energy sources can change over time as a function of underlying scenarios addressing scarcity and technology development. Also, the emissions (greenness) and safety of the different sources will be captured. Company players further decide upon their profit margin and the proportion of their profit devoted to marketing (informing the consumers). The company players can obtain information about the other companies concerning their market share. In making decisions, the company players have the possibility of polling the artificial consumer population to find out about their satisfaction levels.

Two players take the role of political party in the ETG, one currently in the government and the other in the opposition. The government has the possibility of changing the raw prices of the different energy sources by taxing and subsidizing. The opposition party also sets taxation and subsidies. The artificial population evaluates which of the subsidy/taxation regimes is most favorable for them, and they vote accordingly for the party providing them the highest satisfaction level. Political parties have information on their popularity (percentage of voters) and see the elections approaching.

In this paper, we share the experiences we had with playing this game with first-year bachelor students at the University of Groningen (The Netherlands), with young professionals from the energy sector at the University of Tsukuba (Japan), and in a mixed seminar for master and bachelor students with diverse interdisciplinary backgrounds at the University of Osnabrück (Germany).

17.2 Experiences with the Energy Transition Game

17.2.1 Groningen

At the University College Groningen (UCG), we are running a three block ETG project (32 weeks) with 14 first-year students (Fig. 17.2). UCG offers a small-scale educational program in liberal arts and sciences, and the students involved are expected to follow different major directions in their second and third year. The project is aimed to further develop the ETG toward providing a better gaming experience and to include a number of key elements of the energy transition in the game. For June a presentation day has been scheduled where a number of professionals from the energy sector are invited to play the game and provide us with feedback.

Concerning the gaming experience, the students quickly expressed being dissatisfied with the NetLogo version. A key problem appeared to be the limitations of the HubNet possibility, which offered one control screen (Fig. 17.3) and a number of player screens (Fig. 17.4). Whereas the companies could all have separate laptops connected to the game, the political parties (two in our case) had to share the control

Fig. 17.2 Students demonstrating the ETG at University College Groningen

screen. This forced sharing of a screen seriously limited the playing possibilities, especially when two political groups were discussing on what actions to implement. As a consequence we decided to develop the game in Python, creating a platform that we can run on the web, and where different numbers of companies and political parties can be connected using their own computer.

Another critical gaming experience element was referred to the flow of the game, which was absent in the first version. The original model (in default setting) ran too fast, and in combination with the many settings of the energy sources, it was very difficult to see what was actually happening. As a consequence playing the game resulted in frustration because a lot was happening, but the players were having difficulties in understanding how their actions influenced the game. Slowing down the speed of the game and an extensive instruction created better gaming conditions, but we wanted to make the game accessible for first-time players as well without too much instruction in advance. To do so we decided to have the ticks in the game representing a day, and we can vary the speed of the game depending on the level of experience of the players. Most important will be newsflashes. In the NetLogo version, the players should keep a close eye on all the indicators for the different energy sources, and hence a change in the situation was likely to go unnoticed. In the new version every change, such as a different taxation regime, a technological innovation, or a disaster, will be announced by a newsflash in the screen, which will

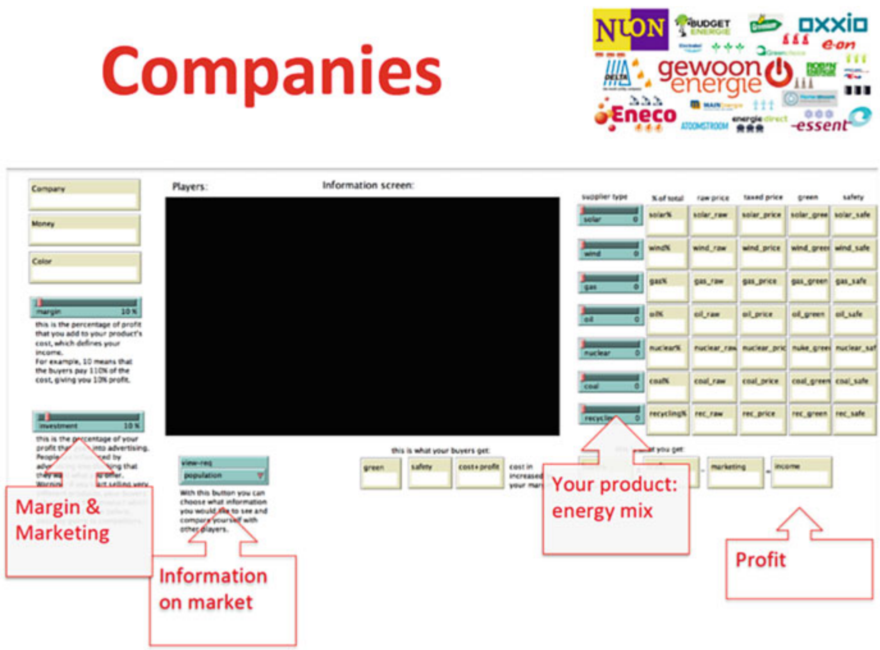

Fig. 17.3 The company screen in the first NetLogo application, highlighting the most important variables

be in the format of a news report. This will support the players to be aware of what is happening in the game and stimulates their thinking about appropriate response strategies, making the gaming a deeper learning experience.

Concerning the key elements of the energy transition, a number of model developments have been initiated in the project. The decision to have ticks of 1 day allows for including both daily weather data as seasonal effects in the model. This allows for developing scenarios of daily and seasonal availability of wind and solar power in the game. The varying ability of sustainable energy will be translated in fluctuating prices of energy, which opens interesting new possibilities. The key expansion of the consumer model will be that the artificial consumers can, next to deciding on energy provider, also decide to invest in private generation and storage of energy (solar panels and battery packs). If for certain consumers this becomes an attractive option, the game would include transitional dynamics of going from a top-down energy market toward a distributed energy system.

The learning aspects of the ETG relate both to developing the game as playing the game. Concerning the current game development project, the students are responsible for developing parts of the gaming context. Hence we have groups focusing at the consumers, at the political parties, at the businesses, and at the technology and disaster scenarios. During the project the students learn about the interconnectedness of these different domains, because they are forced to make

Fig. 17.4 The political party screen in the first NetLogo application, highlighting the most important variables

formal connections in the model. This contributes to deeper level discussions about the complex structure of the energy market and transitional dynamics. In this project setting the ETG serves as a platform for developing transdisciplinary skills.

Because the new version of the ETG is under development, we do not have experience yet with "fresh players" interacting with the game. However, we aim with the ETG to provide a vivid experience with the complexity of the energy system and the interdependencies that make a transition to a low carbon energy system a multidisciplinary challenge. Playing the game can be followed by a group discussion on the energy transition and thus provide an inspiring introduction into the complexities of the energy transition.

17.2.2 Tokyo

At University of Tsukuba in Tokyo, two types of ETG have been conducted during a semester with ten graduate students who were already working in business and had expertise in the energy market. University of Tsukuba in Tokyo offers the systems management-oriented approach for working students of various business fields. The students played a first game of the original ETG developed by University College

Groningen. In the game, they quickly learned strategies to make a profit because they were familiar with more competitive business environments. Although two students played as the parties, their policies were unstable, and the decision-making was turbulent because their operation panel was shared and easily communicated with each other. The second game was played with a modified ETG including aggregators and autonomous players of suppliers with the government except political parties as below.

The electricity crisis and the nuclear accident caused by the huge earthquake in Japan and Fukushima, 2011, clarified that traditional electricity systems on a one-sided energy market are inadequate for maintaining safe and stable electricity supply at low cost. Given such an issue, the government of Japan has clearly announced that it would realize liberation for participation of power operators into small consumers such as general households. It would launch unbundling of power generation and distribution during the period around 2018–2020. This reform, however, entails some risks such as instability of electricity markets and market monopolies, because these are due to a two-sided energy market on a de facto standard platform as well as e-marketplaces.

Therefore, the purpose of the second game is to achieve an efficient market while taking into consideration electricity market liberalization. Additionally, this research studies mechanisms for a competitive electricity markets for enabling energy transformation from fossil energy to renewable energy. In this research, social systems and infrastructures are referred to as the electricity market platform. Here, the focus is placed on aggregators that bring electricity consumers together as a community. We have defined our research objectives as below.

1. To achieve an efficient electricity market while taking into consideration market liberalization.
2. To enable energy transition from fossil energy to renewable energy.
3. To model a decision-making structure of players by applying the agent-based game.

We modified the Electric Transformation Game in order to achieve the research objectives. The modified ETG enables to deal with aggregators and autonomous players of suppliers in addition to consumers. Agent-based game connects agent-based model and serious game. Environmental changes are not deterministic and follow a manner of a complex system.

17.3 Research Objectives

The research objective is to analyze what players can obtain market ascendancy under what kind of conditions in an electricity market. In order to achieve electricity platform design which maximizes social welfare, this research focuses on aggregators and imbalance adjustment. Currently, utilization of market functions associated with electricity supply and demand adjustment has been considered, with

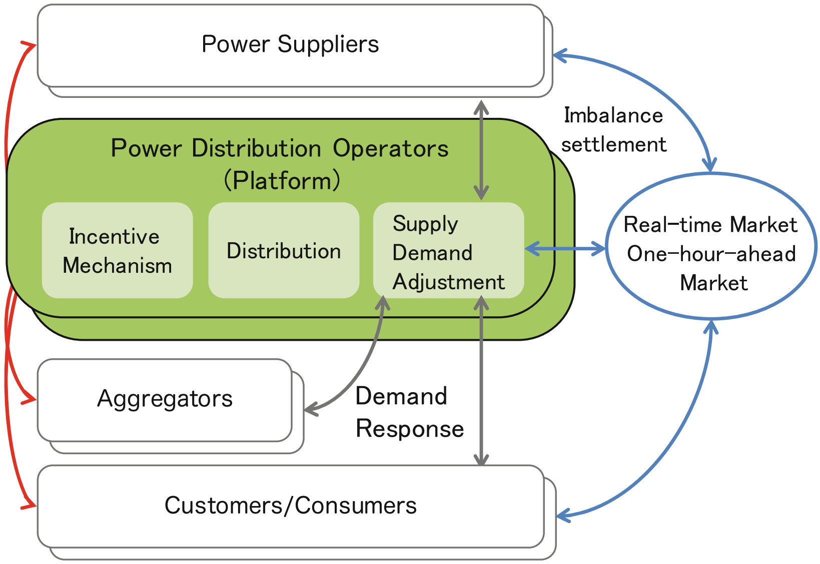

Fig. 17.5 Imbalance settlement and the electricity market

a proposal for establishing a new 1-h-ahead market and a real-time market in order for electricity distribution operators, power producers, and retailers to procure the most efficient regulated power supplies from these markets. Use of these market prices in imbalance settlement for renewable energy can secure transparency and fairness. This should have positive influence on the efficiency of electricity markets and the promotion of renewable energy dissemination (Fig.17.5).

17.3.1 Agent-Based Energy Market Game

In the modified ETG based on agent-based gaming models, the human players participate in the game as power suppliers, retailers, and aggregators.

- Supplier (human/agent player)
- Aggregator (human/agent player)
- The government (human)
- Consumers (agent player)

Suppliers make their decisions based on electricity sale prices, advertising investments, and plans for power generation facilities. Sale prices are adjusted based on imbalance settlement in supply and demand with electricity distribution operators. Aggregators, which serve as a bridge between retail players and general households/operators, are also expected to provide a wide variety of services based on advanced energy management systems by using smart meters. In this gaming model, the actual participants participate in the game playing the roles of power producers, electricity retailers, and aggregators. In addition, computer agents also participate in the market autonomously as consumer agents (Toivonen et al. 2006; Kurahashi and Saito 2013).

17.3.2 Hypotheses

The goal of this study is to clarify decisive factors for making decision of energy selection based on human competitive and collaboration behavior to be helpful for an incentive design of energy markets. For the purpose, two hypotheses were set in the experiment.

First hypothesis Energy transition to renewable energy source is achieved by players while keeping their profit.

Second hypothesis Aggregators have an ability to control the energy market through the share of consumers' power market.

17.3.3 Energy Conversion Gaming Model

In energy conversion gaming models based on agent-based gaming models (Fig.17.6), in an electricity market where power producer players and aggregator players participate, power producers make their decisions based on electricity sale prices, advertising investments, and plans for power generation facilities. Sale prices are adjusted based on the imbalance settlement in supply and demand with electricity distribution operators.

17.3.4 Experimental Results

An electricity gaming model was implemented by the agent programming environments, NetLogo and HubNet, which was operated from each terminal connected to the local network. Figure 17.7 shows the screen displayed for players.

Energy source rate of the whole players In the initial stage, thermal power generation exceeded 60% based on initial settings; however, it declined, finally going down to less than 30%. On the other hand, the proportions of nuclear and renewable energy increased. Energy transition to renewable source seems to be achieved by suppliers.

Consumers' energy preferences This is because of the influence given by the energy preference of consumers. The renewable energy preference gradually increased, while it declined in the later stage. The power generation investments

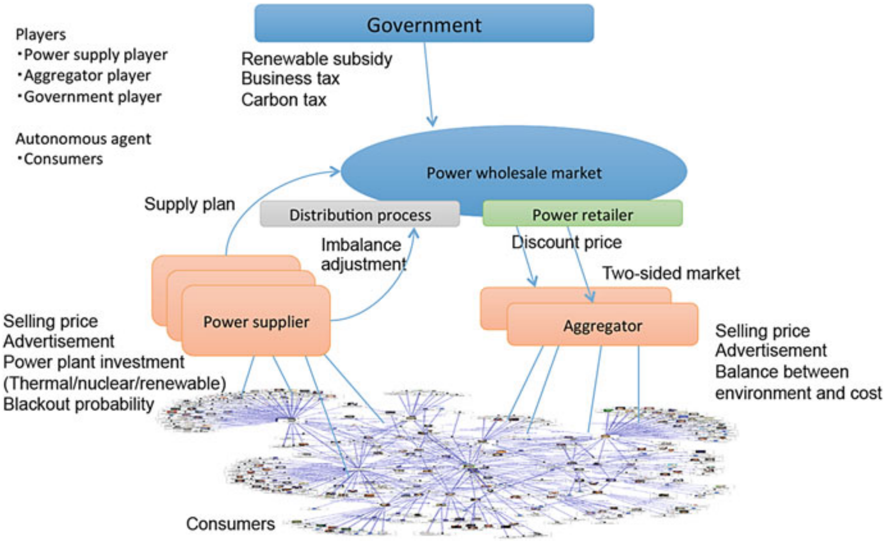

Fig. 17.6 Energy conversion gaming model

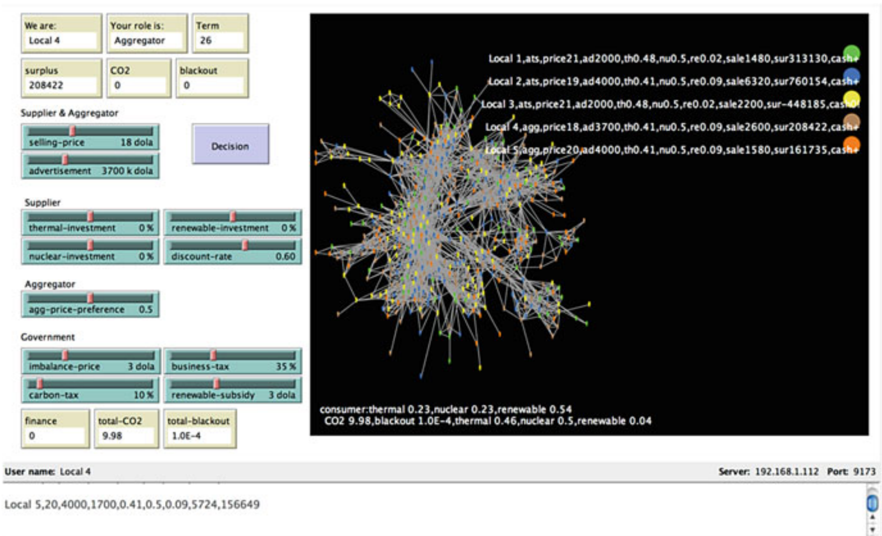

Fig. 17.7 Player panel: Networks of consumers and market shares are graphically observed. Decision-making and management conditions of other players, including the preferences of consumers, are observed on a panel. Decision-making and management condition of all players are able to be observed on a panel in every period

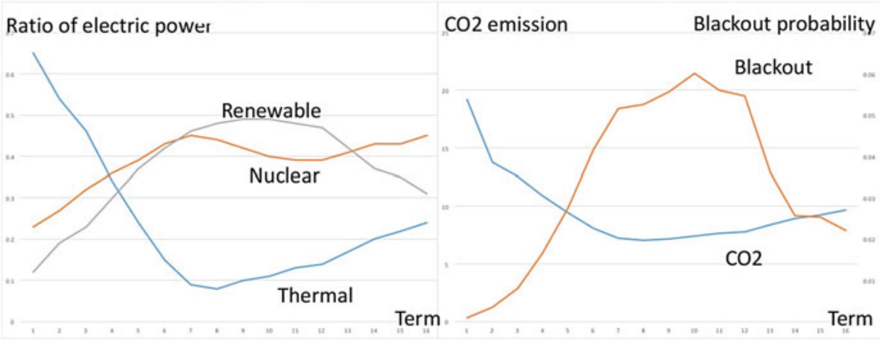

Fig. 17.8 Left: Trend of energy source rate, Right: Trend of CO_2 and blackout rate

were affected by this proportion. Why consumers changed their preference of renewable energy?

CO2 emission and blackout rate The increase of renewable energy reduced the amount of carbon emissions, but it also pushed up blackout rate which made consumers' preference changed. Consumers avoided unstable power suppliers and then changed suppliers from renewable to thermal or nuclear.

Players' sales volume The aggregator agent made profit more than suppliers and controlled the energy market through the share of consumers' power market as well as other two-sided markets.

Energy proportions of aggregator The reason why the aggregator made a profit is that it enabled to change energy source proportions of thermal, nuclear, and renewable energy more quickly than supplier players.

However, the situation, which was originally expected that the proportion of nuclear power generation decreased, was not observed, while nuclear energy with lower cost and carbon gas emissions continue to be relied on (Fig. 17.8). This result shows that the management of electric power suppliers gave the first priority to maximizing their profits while giving almost no consideration to risks of nuclear power generation accidents. On the other hand, the aggregator agent made profit as well as supplier players, but it could not monopolize the electric consumer market because one possibility is that the supplier players learned how to keep their market share in competition from the aggregator (the right chart of Fig. 17.9). The second hypothesis, which aggregators have the ability to control the energy market through the share of consumers' power market as well as other two-sided markets, was rejected with the result.

The result of two hypotheses is the following.

- First hypothesis: adoption
- Second hypothesis: partially adoption

(1) Player's concepts of nuclear accident risks change when they play a social role as entities to make corporate decisions. (2) Aggregator enables to follow

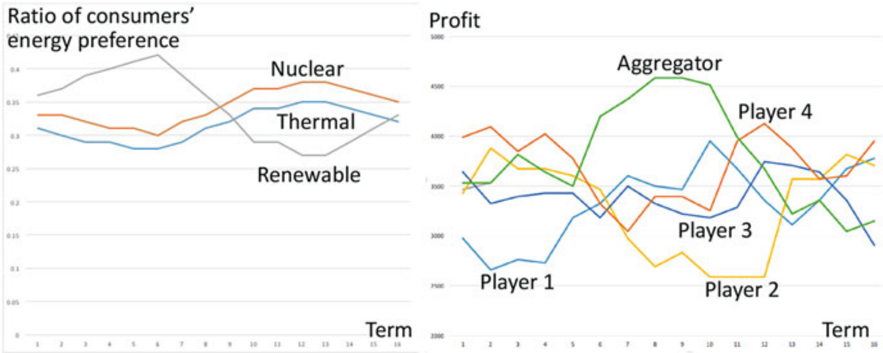

Fig. 17.9 Left, trend of consumers' energy preference; right, trend of players' sales in the power market

consumers' preference quickly and wins in a fluctuated market. It possible to bring about a drastic change to the market. (3) Energy transition to renewable source is achieved by suppliers and aggregators based on lower cost with subsidies, consumers' preference, and power stability.

All the players participating in this experiment were business people in their 1930s, who might have had a custom to make decisions to maximize business profits as corporate managers. They were at the same time consumers; however, this experiment suggests that their concepts of accident risks might significantly change when they play a social role as entities to make corporate decisions.

Our experiment confirmed that the energy orientation of electric power consumers could give a significant influence on power generation investment of electric power suppliers, and the risk of nuclear energy was underestimated. And the first hypothesis was adopted, and the second was rejected by the experiments through the agent-based gaming. These findings enabled us to analyze the decision-making process of people and operators while being able to obtain effective knowledge regarding social ecosystems which disseminate renewable energy and adaptive behavior. In the future, we are going to examine gaming models for system evaluation in liberalized electricity markets including aggregators as electric power wholesalers.

17.3.5 Osnabrück

In Osnabrück, a seminar ran last winter term (2 h per week for 14 weeks). During this course, 26 students played the ETG in three gaming sessions and discussed the ETG and possible improvements in disciplinary settings. Improvements were partly already implemented and tested by the students themselves. Furthermore, group interaction and learning processes were monitored through self-reports.

Students had a diverse background: Most students were on master level and passed different bachelor studies before, such as economics, biology, social sciences, or system science. System science training includes classes about systems and modeling complexity but also math, informatics, and an application subject. The ETG course started with two introductory lectures on the energy transition, common pool resource dilemmas, and agent-based gaming. Afterwards, students played one session to get familiar with the complexity of the game. For the remaining course, two different group settings were crucial: gaming groups and research groups. For the research groups, students selected a scientific disciplinary perspective (scenario/technology, economics/politics, or behavioral sciences). In the research groups students set the agenda together with the teaching staff. The research groups focused on learning more about the respective part of the ETG, how it relates to the real world, and thought about possible improvement. For example, the behavioral sciences research group discussed about the rules simulating agents' behavior and developed alternative rules for certain parts of the ETG. The second group setting was gaming groups, which each represented a company operating in the energy market. The gaming groups were composed of different disciplinary experts from the research groups. Gaming groups met self-organized and developed a strategy for their company, which was rooted in the information of the different disciplinary knowledge acquired in the research groups. The strategies developed in the gaming groups were then tested in two gaming sessions. The course ended with a discussion about experiences and lessons learned.

In the first session, the game was running too fast; thus, we reduced the speed (ticks in NetLogo) to facilitate interaction during the game. Furthermore, we implemented output routines and a Mathematica file suitable to directly display strategies and other values after a game is completed. After every gaming session and in the research groups, students discussed about their experiences and how realistic the ETG is. A summary of critiques to the ETG:

- No branding and building up of reputation possible for the companies (e.g., a high-quality green brand with good service). Service aspects are not considered while being important for choosing an energy company
- It is too easy to change from one energy source to another
- Unlimited capacity of energy sources
- Decision rules: importance of social influence too high
- Setup of the network is based only on income
- Values in scenarios unbalanced, particularly for the German market
- The exact meaning of greenness and safety is not clear
- Companies cannot make negative income

With time the discussion shifted from "what is realistic" to "how realistic should it be to achieve its aim". Students had an intense discussion about the purpose of the ETG, and some students tried to explain that a model should always be made to fit its purpose (e.g., facilitate the experience of certain dynamics) instead of being as realistic as possible. As a result of these thoughts and limited capacities, the research groups focused on what they perceived as useful improvements of the ETG. The following improvements have been implemented so far:

- Students from the scenario/technology group developed a set of scenarios for the German energy market. One of these was chosen by the teaching staff for the last gaming session.
- The setup of network was changed to include the possibility for a second random friend (taking away a link toward the income) to lighten the clustering of similar income agents. While most befriended agents still have a similar income, the change also allows for friends with very different incomes (e.g., parents discussing the energy options with their children). The changes resulted in an easier “break-up” of clusters: other companies could enter new clusters a bit more easy.
- The decision rules of the agents were changed by integrating deliberation and social comparison into one routine. This was done to give consideration to as customers integrating both information from the Internet (deliberation) and social information. Furthermore, students argued that through the raise of the Internet and portals offering comparison, deliberation became a more likely strategy.
- The influence of advertisement was changed to depend upon the satisfaction level of an agent (satisfied agents are less prone to advertisement). This change resulted in a decreased effect of advertisement.
- To simulate the capacity of different energy sources, dynamic prices based on demand were implemented. This was realized through a baseline price for an energy source, which changes with the number of customers using the energy source: The more customers use one energy source, the more expensive it becomes (min 70% of the raw price at 0 demand and 130% at 3*capacity). This change had the strongest impact and increased the difficulty of finding an adequate strategy (increased feedbacks between the strategies).

All changes were discussed and agreed upon by students and teaching staff jointly, preceded by a review about research supporting the assumptions. Furthermore, improvements have been tested in an optional gaming session most students attended. Suggestions for further extensions that could not be addressed in time include:

- Customers should go into deliberation mode when companies change their margin drastically. The most successful strategy to earn money was to set zero margin to gain customers, then set it to 200% until almost all customers had left, and change it back to zero again.
- Accumulated money could be used for investment instead of income in order to come back into the market. If there is no income, you cannot do any investments at the moment.
- If there is a greenness goal and prices are dynamic, investments should be possible to change the capacity of a resource and therefore the real price. For example, increasing the capacity of wind leads to reduced price using the demand function.

From a learning perspective, the ETG course was a success. Both working environments were perceived as positive from the atmosphere, while students diverged in their opinions which one was better/more effective (some students preferred the development of an own applied strategy, while others preferred guidance and input from the teaching staff). The motivational character of the ETG became obvious through student feedback but even more through their commitment. Nearly all students stayed for an optional test game of the implemented improvements. Students brought cake to the sessions, invented new things like lobbyism, and stated to discuss with their friends about the ETG when not in class. The learning that took place was diverse: Several students mentioned the training of social skills, the scenario/technology group learned about the energy transition, while the other groups focused more on other aspects (e.g., strategies of real companies and consumer decision-making). Several students learned specific knowledge such as coding skills, Mathematica, and statistical analysis. Students stated that they found the ETG to be well suited to train about complexity, as already in the first gaming session they noticed how much the success of one strategy depends upon the other strategies chosen. While changing the ETG, the complexity and thereby difficulties to find a promising strategy grew, until discussions about the aim of the game arose.

17.4 Summary and Next Steps

The experiences we share with the game suggest that the ETG can be used and developed in different directions. For a short introduction of the complexities of the energy transition, the game can be played twice in a session of about 2 h. After a generic introduction, the students can pick a role and play the game for the first time. For this application it is critical that the game is easy to understand, that information is easy to find but not overwhelming, and that the speed and actions in the game are such that players experience a flow. After a first game, a reflective discussion can take place, and if the goals of reducing emissions have not been reached, a discussion can be initiated about which policies and agreements the players suggest to improve the collective performance in terms of emission reduction in the next gaming session. After a next gaming session, a concluding discussion can take place addressing the experiences of the players and reflecting on the complexities of the energy transition.

Another possibility in playing the game involves developing a project in which students develop and parameterize the game as done in Groningen and Osnabrück. This would, for example, open the possibility of having groups working on the construction of the artificial population using theory and additional (collected) data, developing scenarios for technology development (e.g., smart grids), scarcity of resources and possible disasters, and the political context. Such a setup creates a project in which students can address different disciplinary perspectives in further developing the game, but they will have to collaborate because their perspectives have to be formally connected in the model. Hence a project like this creates natural conditions for the support of a multidisciplinary learning experience. Another advantage of students codeveloping the ETG is their increased motivation and ownership, allowing for an active and self-steered learning experience.

The ETG is also useful as basis for further extensions and testing of specific hypotheses, as done in Tokyo using aggregators as intermediate agents.

To specify and adapt the ETG offers the possibility to adjust it to specific needs (e.g., national energy market characteristics or a specific research question). In the different test cases, various improvements and specifications have been and will be implemented. As a result, it becomes more difficult to compare and integrate the different versions. For example, the Python version to be developed in Groningen will enable nonexpert users to easily interact with the game while turning it more difficult to adapt the game for specific settings in student projects. We consider a common platform for different versions (e.g., on openABM) a sensible next step, including a version control and description of different implementations. An additional description of game dynamics could help to consciously choose an implementation for a specific purpose. Finally, another interesting way forward could be to develop standardized questionnaires and conduct a systematic comparison of learning experiences with the ETG.

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Chapter 18
A Coevolutionary Opinion Model Based on Bounded Confidence, Reference Range, and Interactive Influence in Social Network

Chao Yang

Abstract The rapid development of Web 2.0 technology has made social network platform become an important place for opinion generation, exchange, and dissemination. Thus, the study of opinion evolution via social network has important theoretical and practical significance. In this paper, we propose an coevolutionary opinion model of social network based on bounded confidence, reference range, and interactive influence. First, a dual opinion structure is defined, which considers both inward attitude and outward appearance to reflect the constitution and expression of individual opinion. Second, the interactive mechanisms between individuals are captured through two types of social relationships as authority and familiarity. Then, each individual is assigned a reference set and a trust set based on the individual influence model and bounded confidence model. In order to connect the micro-opinion update behavior and macro-network evolution phenomenon in such situation, an agent-based coevolutionary opinion model is proposed based on multidimensional time-varying interactive influence of users. Three groups of simulation experiments have been conducted to compare the system dynamics under different values of confidence threshold, reference set size, and social relationship influence. The obtained results are found in good agreement with what has happened in the bounded confidence model, but more accord with the people behavior characteristics of opinion interaction under the network environment, which would help us to better understand the internal mechanism of opinion dynamics and social network evolutions.

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18.1 Introduction

In recent years, with the rapid development of Web 2.0 technology and social network service, mass contingency events caused by opinion spreading and emotion gathering appear to be on the rise. Thus, the study of opinion evolution via social network has important theoretical and practical significance to construct a positive environment for the harmonious development of society.

Generally, individual opinion of the social network refers to people's view of a certain thing or problem, and then the same or different views together form the public perspective in the whole network. With a bottom-up perspective, if taking the individual and opinion as a node and a label separately, then the opinion evolution process is essentially a complex network with its nodes' labels and the edges between nodes changing over time, the key problem is the representation of label and the changing mechanism of edges. Therefore, we take the following several aspects into account and propose our agent-based model for exploring complex opinion evolution process of social network.

First, from the angle of opinion constitution, individual opinion includes inward attitude and outward appearance, and it also involves heterogeneous personal characteristics. Therefore, the definition of opinion structure should not only capture but also naturally connect and describe the complex relation between people's inner attitudes and external appearance, which is corresponding but not equal. Second, from the micro-perspective of opinion evolution, when people update their opinion, they always trust the high-effect people and get those similar viewpoints among them. Therefore, individual influence strength and bounded confidence threshold should be considered in representing the individual characteristics. Third, from the macro-perspective, the interactive network structure involves either explicit or implicit social relationships between two individuals. The social network structure is changing over time based on the individual interaction via different relationships, leading to that the influence between individuals show a time-varying feature in return. Such interactive mechanism and feedback should also be considered into the opinion evolution model.

In this paper, we consider the above mentioned aspects and propose an opinion evolution model of social network based on bounded confidence, reference range, and interactive influence. The rest of this paper is organized as follows: Sect. 18.2 briefly reviews the related research works on opinion evolution model of social network; Sect. 18.3 introduces the main concept and key subprocess of our proposed agent-based opinion evolution model; Sect. 18.4 gives the experimental setup and results; then Sect. 18.5 discusses the results; and, finally, Sect. 18.6 concludes our work and presents the future works.

18.2 Related Work

There have been lots of research works concerning the opinion evolution model of social network. In the literature, the typical bounded confidence model such as Deffuant model (Deffuant et al. 2000) and Hegselmann-Krause (HK) model (Hegselmann and Krause 2002) defines a distance threshold, and individuals update their opinions at discrete time point according to others' views within this threshold. The evolution results of Deffuant model show that the final number of opinion clusters (a group of individuals with the same view) is inversely proportional to the distance threshold. And HK model using different forms of weighted matrix can present a variety of evolution features of public opinions. Kurmyshev et al. analyze the limitations of the Deffuant-Weisbuch (DW) bounded confidence model and propose a mixed model which defines two psychological types of individuals as concord agent and partial antagonism agent, in order to investigate the opinion dynamics in heterogeneous agent groups under different social network structure (Kurmyshev et al. 2011). They find that group opinion formation is almost independent of the topology of networks used in this work, and opinion fragmentation, polarization, and consensus are observed in the mixed model. Further, Su et al. extend the HK model and investigate the coevolution of opinions and observational networks. They conclude that the tendencies of average of opinion clusters, consensus probability, and average of convergence rounds are similar on both the static networks and adaptive networks (Su et al. 2014).

On the other hand, the continuous opinions and discrete actions (CODA) model takes into account the individual inward view and outward behavior (Martins 2008a). It is not only more accurately describing corresponding but unequal relation between people inner attitudes and external appearance but also can be used to capture the observer bias in the process. Further, the model proposer Martins carries out simulation experiments under different network structure, individual heterogeneity, and pure continuous opinion and even adds the variables of the impact on the neighbors, in order to study the emergence of extremism in social network. He concludes that strengthening the interaction helps to reduce extremism (Martins 2008b; Martins and Kuba 2010). In addition, Diao et al. propose a dynamic opinion model based on expanded observation ranges and individuals' social influences in social networks (Diao et al. 2014). They point out that the intensity of each interaction is negatively correlated with observation range, while the stability of each individual's opinion positively affects the correlation.

Besides, Axelrod's cultural dissemination model mainly studies the spread characteristics of multidimensional culture (Axelrod 1997). Axelrod model assumes that similar individuals are more likely to influence each other, while the influence increases the similarity between individuals in return. He then studies the impact of cultural dimensions, cultural attribute, the number of neighbors, and the size of the grid on the evolution and formation of culture area. Due to the cultural characteristics that can be regarded as discrete vector, the similarity is then calculated by hamming distance. Further, researches of De Sanctis and Galla (2009) and Gracia-

Lzaro et al. (2011) add the threshold mechanism on the basis. In fact, information exchanges based on similarity and based on threshold are two different interaction mechanisms: in the former case, as long as the similarity is not zero, then they will have the opportunity to interact, while in the latter case, only the similarity is smaller than a certain hamming distance will trigger interaction. Threshold is conducive to the interaction of similar views and meanwhile guarantees the difference, which reflects the thoughts of "harmony in diversity."

The literature review shows that the opinion evolution modeling of social network is a very complex process and a realistic model should take into account multidimensional interactive influence such as the individual's inner attitude and outward appearance, the interactive influence through multiplex social relationship, the bounded confidence, and feedbacks between the opinion dynamics and network evolutions.

18.3 Model Description

In this paper, we propose a coevolutionary opinion model of social network based on bounded confidence, reference range, and interactive influence. First, a dual opinion structure is defined, which considers both inward attitude and outward appearance to reflect the constitution and expression of individual opinion. Next, suppose the individual interaction network at time t is W_t and the current executor agent is A_i, then the model carries out the following steps: (1) calculate other agent's interactive influence on A_i; (2) construct A_i's reference set; (3) construct A_i's trust set; and finally (4) update A_i's opinion and the interactive network W_t.

Below we will introduce the main concepts and key subprocesses of our agent-based opinion evolution model.

18.3.1 Expression of Individual Opinion

The individual opinion is defined as a dual structure which consists of both inward attitude and outward appearance. Set the total number of agents as N; each agent has D-dimensional inward attitudes and outward appearance titled as InValue and OutValue, respectively. At each dimension, the value of InValue ranges from -1 to 1, and OutValue is a binary variable, either 0 or 1. Assume that individuals generate their opinions after a complex process of continuous inner attitude accumulation and finally only the outward appearance could be observed, we then measure the individual opinion dynamics by using the outward value. For easy comparison, we convert the binary representation of multidimensional outward appearance to a decimal value V, where $V \in [0, 64]$.

18.3.2 Calculation of Individual Interactive Influence

The key process of opinion evolution under a network environment is how to determine the source of opinion among a lot of users, namely, how to select the opinion source through the social influence. In this paper, we define two kinds of user's interactive influence according to the strength of interaction relations as authority and familiarity. Suppose there are three individuals: A, B, and C. If A has ever been trusted by B and C many times and B and C also often trust each other but A never or rarely trusts B and C, in such case, the relationship of A for B and C is authority, and the relationship between B and C is familiarity. The social network structure is changing over time based on the individual interaction via different relationships, leading to that the influence between individuals show a time-varying feature in return. Below, we define two equations which calculate the strength of each kind of relation that an agent A_i acts on another agent A_j:

$$\text{Familiarity}_{t,i}(A_j) = \frac{w_{t,ji} + w_{t,ij} + \lambda}{\sum_{k=1}^{N}(w_{t,ki} + w_{t,ik} + \lambda)} \tag{18.1}$$

$$\text{Authority}_{t,i}(A_j) = \frac{\sum_{k=1}^{N}(w_{t,jk} + \lambda)}{\sum_{l=1}^{N}(\sum_{k=1}^{N} w_{t,lk} + \lambda)} \tag{18.2}$$

where $w_{t,ji}$ is the element of matrix W in the line i and column j, corresponding to the number that A_i has updated his view according to the opinion of A_j before time t. λ is the interference parameter, and its role is in twofold: (1) to ensure the denominator of formulas (18.1) and (18.2) not be zero in the simulation process, so as to prevent the floating point arithmetic overflow, and (2) to adjust the impact strength of influences by changing the value of λ; the bigger the value of λ, the smaller the strength. When λ tends to infinitesimal (0.00001), the strength of influence is relatively large. When λ tends to infinity $(10,000)$, the probability of each agent to be selected tends to be the same, which indicates that the model will ignore such interactive influence.

18.3.3 Construction of Reference Set

In the model, we set that each agent only considers other L agents with larger influence and define the L agents set as his reference set, where L is the length of reference set and its scope is $[1, N)$. According to the two types of individual interactive influences, A_i's reference set at time t is defined consisting of top L agents with either largest familiarity strength or largest authority strength, calculated and ranked by Eqs. 18.3 and 18.4, respectively:

$$\text{Reference}_t(A_i) = \{j|A_j \in \text{Top}_{j,t}(L, Fa), j \in N\} \tag{18.3}$$

$$\text{Reference}_t(A_i) = \{j|A_j \in \text{Top}_{j,t}(L, Au), j \in N\} \tag{18.4}$$

where $\text{Top}_{i,t}(L, Fa)$ and $\text{Top}_{i,t}(L, Au)$ represent two sets which consist of top L agents with largest familiarity or largest authority on A_i at time t. Therefore, larger L means that A_i intends to consider more other agents' views. In the case that L is equal to N, all agents enter into the reference set, which actually ignore the action of constructing reference set.

18.3.4 Construction of Trust Set

In this step, the model sets that agent only trusts those agents in his reference set and with a distance between their outward views smaller than a predefined confidence threshold. Confidence threshold ϵ represents the size of acceptable difference between various opinions, and it is the key parameters for deciding the length of trust set. Confidence threshold ϵ ranges from zero to D. On this basis, the trust set at time t is constructed as below.

$$\text{Trust}_t(A_i) = \{j|\text{HamDis}_t(A_i, A_j) \leq \epsilon, j \in \text{Reference}_t(A_j)\} \tag{18.5}$$

where $\text{HamDis}_t(A_i, A_j)$ calculates the hamming distance between A_i and A_j's outward appearance represented by binary. Obviously, the trust set of A_i consists of those agents with their OutValue distances smaller than ϵ. Therefore, the greater the ϵ is, the agent A_i is easier to accept others' view. If ϵ is equal to D, all agents in the reference set are also in the trust set, hence omitting the step of constructing trust set.

18.3.5 Update Opinion and Interactive Network

After constructing reference set and trust set, we set that agent will update their values of InValue and OutValue according to Eqs. 18.6 and 18.7:

$$\sum_{d=1}^{D} \text{InValue}_{t+1,d}(A_i) = \frac{\sum_k^{\text{Trust}_t(A_i)} \text{Invalue}_{t,d}(A_k) * \text{Influence}'_{t,i}(A_k)}{|\text{Trust}_t(A_i)|} \tag{18.6}$$

$$\sum_{d=1}^{D} \text{OutValue}_{t+1,d}(A_i) = \begin{cases} 0 & \text{Invalue}_{t+1,d}(A_i) < 0 \\ 1 & \text{Invalue}_{t+1,d}(A_i) \geq 1 \end{cases} \tag{18.7}$$

where $\text{InValue}_{t,d}(A_i)$ and $\text{OutValue}_{t,d}(A_i)$ are the d-th dimensional inward or outward view of A_i at time t and $\text{Influence}'_{t,i}(A_k)$ is the normalized influence of agents in the trust set. A_i will update the value of InValue according to the combined effect of agents' InValue in his trust set and update his OutValue according to the new InValue. Finally, we update the interaction network as Eq. 18.8:

$$\sum_{k}^{\text{Trust}_t(A_i)} w_{t+1,ki} = w_{t,ki} + 1 \tag{18.8}$$

18.4 Experimental Setup and Results

18.4.1 Experimental Setup

In this paper, we execute three groups of experiments to investigate how (1) the confidence threshold ϵ, (2) the reference set size L, and (3) the interactive influence affect the opinion evolution results. The evolution results are measured by (1) the number of iteration times when the evolution system reaches a stable state and (2) the number of opinion clusters when the evolution system reaches a stable state. Table 18.1 summarizes the method of three groups of experiments. For each group of experiments, we also draw the curves of individual outward opinion over time.

Table 18.2 gives the alterable parameter settings of experiments, and Table 18.3 is the common parameter settings.

Table 18.1 Description of three groups of experiments

Experiment	Purpose	Measurement
1	The impact of confidence threshold λ	The number of iteration times
2	The impact of reference set size L	The number of iteration times
3	The impact of interactive influence	The number of iteration times/ The number of opinion clusters

Table 18.2 Alterable parameter settings of experiments

Experiment	Parameter setting	
1	λ= 10,000, L = 100, ϵ = {1, 2, 3, 4, 5, 6}	
2	λ = 10,000, ϵ = 3, L = {2, 5, 10, 20, 50, 100}	
3	Random reference	ϵ = 3, L = 5, λ = 10,000
	Familiarity influence	ϵ = {3, 6}, L = {5, 10}, λ = 0.00001
	Authority influence	ϵ = {3, 6}, L = {5, 10}, λ = 0.00001
	Mixed influence	ϵ = 3, L = 5, λ = 0.00001

Table 18.3 Common parameter settings of experiments

Parameter	Value	Description
Agent number N	100	The agent number in total
Opinion dimension D	6	The dimension of opinion of each agent
Each dimension of InValue	$[-1, 1]$	The inward view with D dimension which represents inner attitude
Each dimension of OutValue	InValue $> 0?1 : 0$	The outward view with D dimension which represents outer appearance
Iteration times	50	The iterated times of each trial

18.4.2 The Impact of Confidence Threshold λ

In this experiment, we investigate the impact of confidence threshold λ on opinion evolution. Figure 18.1 gives the change curve of opinion of all agents over time under different λ.

The results in Fig. 18.1 show that the number of opinion clusters when the system reaches a stable state decreases with the increase of confident threshold ϵ in our model, which is consistent with the conclusion of classical bounded confidence model – the number of opinion clusters is inversely proportional to the threshold. We also obtain that the confidence threshold which is equal to 3 is the critical value that the system is able to form a consistent opinion.

18.4.3 The Impact of Reference Set Length L

This experiment explores the impact of reference set size L on opinion evolution by fixing ϵ to 3. Figure 18.2 draws the opinion change curve of all agents under different L. The results in Fig. 18.2 show that the increase of the reference set length L could speed up the system convergence to a stable state and reduce the last number of opinion clusters. Especially, when L is greater than 10, the effect of the parameters on the opinion evolution becomes limited, and the required iteration number of the system reaching a stable state is random values under different L.

18.4.4 The Impact of Individual Interactive Influence

This group of experiments examines how the interaction influence between users affects opinion evolution. We first set up $\epsilon = 3$ and $L = 5$ and then consider four ways to construct the reference set: (1) the model randomly selects L agents to build up the reference set; (2) the reference set consists of the top L agents ranked by largest familiarity influence; (3) the reference set includes the top L agents with

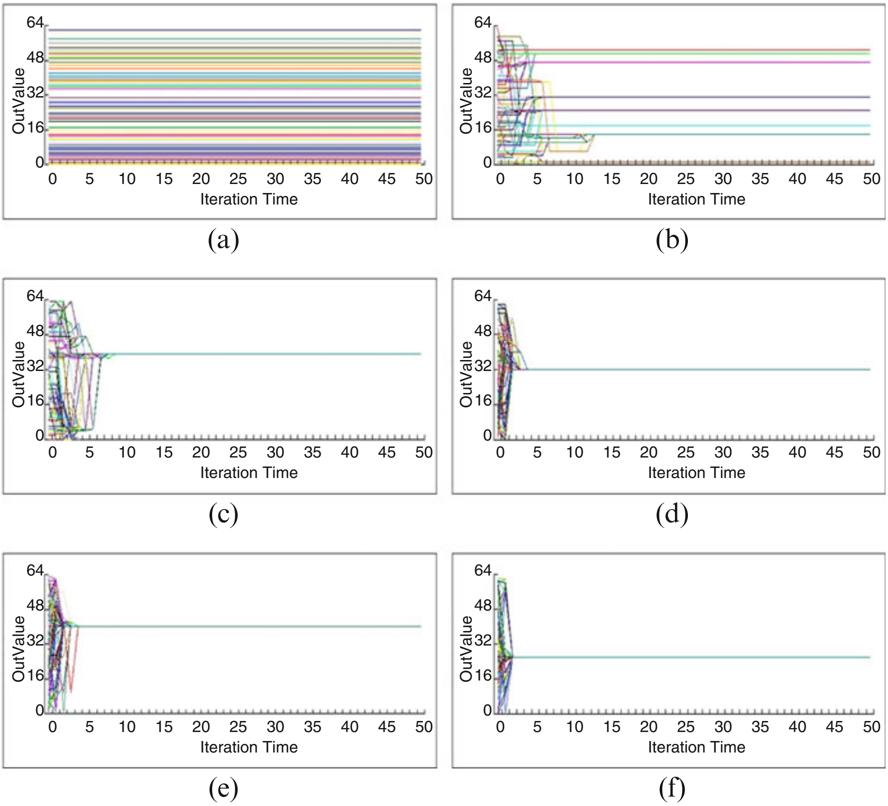


Fig. 18.1 The change curve of all agents under different ϵ. (**a**) $\epsilon = 1$. (**b**) $\epsilon = 2$. (**c**) $\epsilon = 3$. (**d**) $\epsilon = 4$. (**e**) $\epsilon = 5$. (**f**) $\epsilon = 6$

largest authority influence; and finally, (4) the reference set is composed of the top $L/2$ agents with largest authority strength and the top $L/2$ agents with largest familiarity strength.

The opinion change curve of all agents and the corresponding interaction network under different reference set is shown in Figs. 18.3 and 18.4, respectively.

The obtained results are as follows:

1. When the reference set is composed of five random agents without considering interactive influence, the opinion change curve shows that the interactions between agents are very drastic and opinions change frequently. When the simulation moves forward, all the agents gradually differentiate into three interactive groups, and agents in each group finally form their uniform opinion, respectively.
2. When the reference set is composed of top five agents with largest familiarity strength, the opinion change curve shows that the system is difficult to reach a stable state. We also find many circles of the interaction network. Meanwhile, the

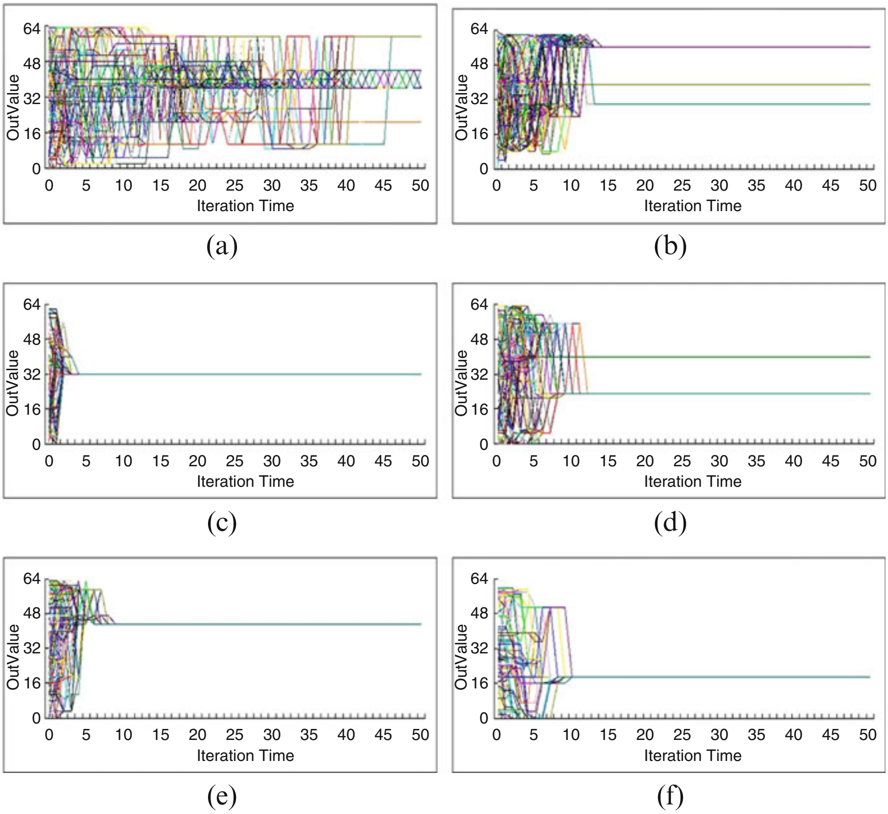


Fig. 18.2 The change curve of all agents under different L. (**a**) $L = 2$. (**b**) $L = 5$. (**c**) $L = 10$. (**d**) $L = 20$. (**e**) $L = 50$. (**f**) $L = 100$

agents 83, 69, and 56 have great out-degree, but most of the agents have small out-degrees.

3. When the reference set is composed of top five agents with largest authority strength, the opinion change curve shows that the system fast evolves to a stable state. We have observed opinion polarization of the interaction network. Meanwhile, the agents 31, 41, 61, 92, and 15 have great out-degree, but most of the agents have small out-degrees. There also exist few agents that follow nobody and keep its nonmainstream opinion.
4. In the last case, familiarity and authority individuals, respectively, make up half of the reference set. Compared with the former cases, the system could achieve a stable state, and the required iteration times are greater than authority case but smaller than random case. At the same time, the interaction network has both rings and asters, which is corresponding to its comprehensive reference set.

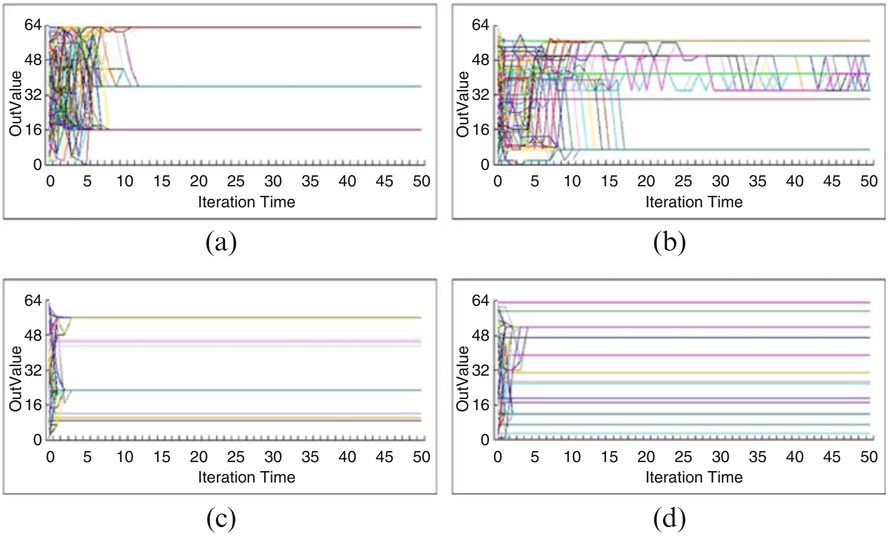


Fig. 18.3 The change curve of all agents under different individual interactive influences. (**a**) Random reference. (**b**) Familiarity influence. (**c**) Authority influence. (**d**) Mixed influence

18.5 Discussion of the Results

Further, we discuss the simulation results as follows:

1. The results of the first experiments show that the number of opinion clusters when the system reaches a stable state decreases with the increase of confident threshold ϵ in our model. This is because larger threshold indicates more loose condition for agent trusting others, that is, agent could refer to more other agents, which makes the system reach a stable state quickly and reduce the number of opinion clusters and even finally converge into a unique opinion cluster. Especially, the critical value of confidence threshold (ϵ equals to 3) indicates that too small confidence threshold will not form public opinions on the social network.
2. The results of the second experiments show that the number of opinion clusters when the system reaches a stable state decreases with the increase of the reference set length L in our model. This is because the increase of the reference set length L could also promote the interaction between different agents, then speed up the system convergence to a stable state, and reduce the last number of opinion clusters. Due to the too large values of the reference set length, the number of iterations required by the system to reach a steady state is fluctuation.
3. The results of the third group of experiments show opinion convergence, fluctuation, and polarization under different compositions of reference set. An interesting phenomenon is that the system convergence is much fast under authority reference but it is difficult to form opinion clusters under familiarity

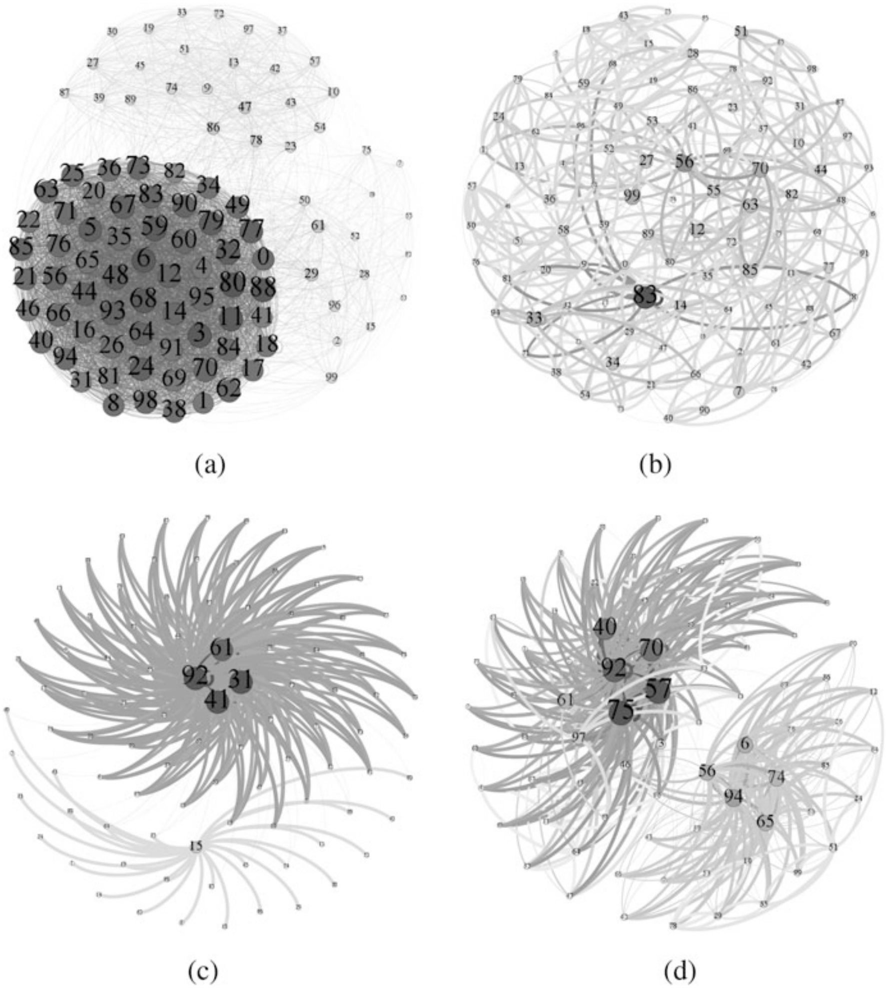
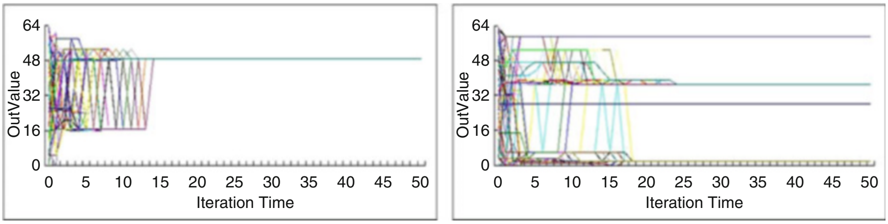


Fig. 18.4 Interaction network under different individual interactive influences. (**a**) Random reference. (**b**) Familiarity influence. (**c**) Authority influence. (**d**) Mixed influence

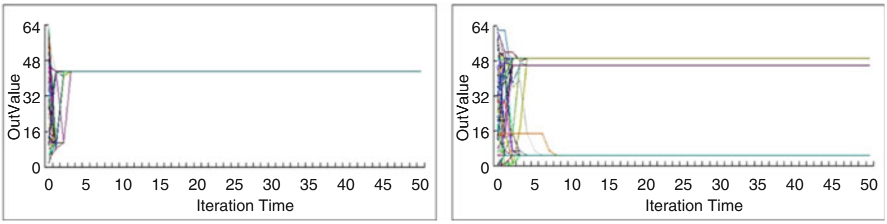
reference. This result could be explained by the calculation process of two types of individual interactive influence, in which authority influence has a global effect of system opinion evolution, while familiarity influence has only local effect which is actually decreasing the convergence rate of system. In order to make the results more credible, we further increase the values of confidence threshold ϵ and reference set size L, respectively, and observe the evolution of opinion, shown in Figs. 18.5 and 18.6.

The obtained results in Fig. 18.5 show that the increase of reference set length ($L = 10$) could make the system shift from an unstable state to a stable state and



(a) (b)

Fig. 18.5 The change curve of all agents after increasing the ϵ and L under familiarity reference. (**a**) $\epsilon = 3$, $L = 10$. (**b**) $\epsilon = 6$, $L = 5$



(a) (b)

Fig. 18.6 The change curve of all agents after increasing the ϵ and L under authority reference. (**a**) $\epsilon = 6$, $L = 2$. (**b**) $\epsilon = 3$, $L = 10$

even form a uniform opinion. However, the increase of the confidence threshold ($\epsilon = 6$) cannot achieve such result. This is because when the reference set is relatively short, the number of referred familiarity agents is rare; thus, even increasing the threshold could not enhance the interaction between agents. In contrast, when the confidence threshold is set too small, two agents with great familiarity may be difficult to trust each other. But the larger size of reference set involves more other familiarity agents, and then quantitative change may cause the qualitative change, leading to more interaction between agents, thus promoting the system to a stable state.

The results in Fig. 18.6 show that when the reference set only consists of authority agents, then increasing the confidence threshold ($\epsilon = 6$) could make the system reach a final stable state and form a uniform opinion cluster, while increasing the length of the reference set ($L = 10$) cannot achieve this result. On the one hand, if the confidence threshold is relatively small, then even increasing the number of referable authority agents, the agents in different clusters would not exchange their views because of the too large difference, and thus decrease the number of agents with same opinion. On the other hand, the number of referable authority agents is decreased when reference set length is smaller, increasing the confidence threshold would lead agents easily to trust authority agents and promote the exchange of views among them, and finally all the agents come to a uniform view quickly.

4. Compared with the former cases, the results of the last experiments show that the system could achieve a stable state, and the required iteration times are greater than authority case but smaller than random case. Meanwhile, the interaction network has both rings and asters, which is corresponding to its comprehensive reference set. The authority influence has a global effect of system opinion evolution, and familiarity influence has a local effect, which together determine the final system evolution result.

18.6 Conclusion and Future Work

In this paper, we propose an opinion evolution model of social network based on bounded confidence, reference range, and interactive influence. First, a dual opinion structure is defined, which considers both inward attitude and outward appearance to reflect the constitution and expression of individual opinion. Second, the interactive mechanisms between individuals are captured through two types of typical social relationships as authority and familiarity. Then, each individual is assigned a reference set and a trust set based on the individual influence model and bounded confidence model. Further, in order to connect the micro-opinion update behavior and macro-network evolution phenomenon in such situation, an agent-based opinion evolution model is proposed based on multidimensional time-varying interactive influence.

Three groups of simulation experiments have been designed and conducted to observe the opinion evolution dynamics and system states under different values of confidence threshold, reference set size, and interactive individual influence. The obtained results show that the model could reproduce the convergence, fluctuation, and polarization of opinion evolution. In particular, the opinion consistency under familiarity influence is not so good; the system cannot reach a stable state or requires a long time to reach a final stable. Under this case, the interaction network forms many rings. Meanwhile, the interactive influence based on authority obtains a better opinion consistency, and the time to reach stable is short. Under this case, the simulation model forms an aster-shaped interaction network. Compared with the classical opinion evolution model, the proposed new model is more natural for people's opinion interaction behavior under the network environment, which would help us to better understand the internal mechanism of opinion dynamics and social network evolutions.

One limitation is that the proposed model in this paper considers the unified experimental settings of parameters as reference set length, confidence threshold, and the individual interactive influence, which do not reflect the difference and personalization of individual. In the next work, we will take into account the individual heterogeneity and expand the scales of individual interactive influence. We hope all of these efforts will contribute to make our agent-based opinion evolution model of social network more efficient and natural in real practice.

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Chapter 19
Prof. Dr. Takao Terano as a Brilliant Educator

Takashi Yamada

Abstract This article reviews the activities of Prof. Dr. Takao Terano's laboratory at Tokyo Institute of Technology and briefly introduces several representative papers especially in social simulation literature. The social simulation studies belong to one of the two aspects, applications and fundamentals. The former include financial markets and systems, organizations, network, movement of people, and educational systems. The latter deal with large-scale simulations and real-time data aggregation.

19.1 Introduction

Prof. Dr. Takao Terano started to take up his new post at Tokyo Institute of Technology (Tokyo Tech)[1] in 2004, being moved from the University of Tsukuba, and worked there for over a decade. During his career in Tokyo Tech, Prof. Dr. Terano not only progressed his research and created new research fields in, for example, educational engineering but also coached the younger generations in agent-based social system science, knowledge systems development, evolutionary computation, and service sciences. As a result, a total of over 80 students including those who are attending as of August 2017 have studied under him, and hundreds of papers have been published.

This article reviews some of the representative work by focusing on social simulation studies which include markets, organizational behaviors, networks, movement of people, and education as applications. Moreover, a couple of other

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related works are on foundations of social simulations such as large-scale simulation platform and real-time data processing. The author hopes that readers may find that the work covers a wide variety of topics and consider them as state-of-the-art, universal, and fundamental.

The remainder of the paper is organized as follows: The next section introduces the activities of Prof. Terano laboratory. Section 19.3 reviews the representative work in social simulation. Finally, Sect. 19.4 concludes.

19.2 Prof. Terano Laboratory

Members in Prof. Terano laboratory (Terano lab hereafter) were mainly divided into two parts, master's course students and doctoral course students, because DCISS is a graduate school. But, students in bachelor course are occasionally allowed to study for their graduation work when they want and their affiliation gives a permission. Also, Prof. Terano has invited a few visiting professors, and they also bring in prospectus students. Dr. Atsushi Yoshikawa, Dr. Gaku Yamamoto, and Dr. Yoichi Motomura have jointly worked with Prof. Terano. With respect to the master's course students, a regular professor can take in five students at most in a fiscal year, and a visiting professor does at most three. Therefore, in some fiscal years, he needs to take care of five or more students and assign research tasks to them. On the other hand, there are no restrictions on the number of students in doctoral courses in a fiscal year. Consequently, not only full-time students but also international students and working students have enrolled.

Table 19.1 is the breakdown of the current and alumni members. Note that those who completed Ph.D. program without a Ph.D. degree are not included. The reason why there have been several international students in bachelor course is that Prof. Terano has accommodated international exchange students as an international strategy of Tokyo Tech. One prominent characteristic is that Terano lab has had many working and international students. As to working students, his former affiliation, University of Tsukuba, Tokyo Campus, is for only working students. For this reason, most of the Ph.D. holders are working or international students.

Coaching for master's course students is as follows: before their enrollment (after passing the exam), they are invited to take part in a reading seminar where they are asked to read a designated textbook and give a lecture of the corresponding contents in turn. The books are usually about how to write academic papers such as Rossiter (2004) and Sugihara (2001). After their enrollment, they participate a seminar once a week as well as attend lectures. Before starting their research project, they are to read master's theses of earlier laboratory members so that they learn to know what has been studied in the laboratory and what kind of skills they should have. At the same time, they also attend another reading seminar jointly with Prof. Dr. Kastumi Nitta where the students tackle with the Japanese edition of "*Artificial Intelligence: A Modern Approach*" by Stuart Russell and Peter Norvig in the summer semester (Russell and Norvig 2002). Moreover, they are encouraged

Table 19.1 The number of current and graduated members in Terano lab as of August 2017

	Bachelor		Master		Doctor		
	(JPN)	(INT)	(JPN)	(INT)	(JPN, full)	(JPN, working)	(INT)
2006	1	0	1	0	0	0	0
2007	0	0	2	0	0	2	0
2008	1	0	7	0	0	2	0
2009	0	0	2	0	0	3	1
2010	0	0	5	2	1	0	0
2011	0	0	4	1	0	4	1
2012	0	0	4	0	0	1	1
2013	0	0	6	0	0	0	1
2014	0	1	2	0	0	0	3
2015	0	6	3	1	0	0	4
2016	0	0	1	1	2	1	1
2017	0	0	0	0	1	2	1
Current	2	2	9	3	0	8	2
Total	4	9	46	8	4	23	15

to attend the weekend seminar which is originally held to working students. In late summer or early autumn, students go a study camping and a factory tour, which is an expanded version of weekend seminar, so that they make a presentation about their research plan to develop and improve the ideas and are encouraged to learn goods-producing fields. In late autumn, they also go for a study camping where several laboratories in DCISS get together and exchange ideas of their research project. In January of their first year, they talk their research shortly in the official workshop of DCISS. In their second fiscal year, they are required to progress their research, report periodically, and, if possible, write an article for conference presentation or to a journal. When necessary, they can learn firsthand from Prof. Terano. After a study camping of laboratory, they give a second official talk in autumn. Finally, they finish and submit their master's thesis in late January and make a presentation in early February.

Coaching for doctoral course students, especially working students, is rather different. They are only asked to progress their study and report periodically because they do not have to attend classes at all. The necessary requirement for Ph.D. degree in DCISS or Tokyo Tech is students should have at least two journal articles and an English presentation in a workshop or a conference. Moreover, there are several steps to complete this: first, they make a first official talk for 15 min in DCISS when their work is accepted for publication. Then, when they satisfy the abovementioned requirement, they once again make a second official talk for 30 min. After passing the process, they face a public hearing with their dissertation. Finally, they take the final exam based on the questions and the comments in the public hearing.

Prof. Terano's principle of guidance consists of the following two points: developing the merits of students and avoiding overcoaching. They are what educators are required to have and what Prof. Terano has considered as important.

19.3 Representative Studies in Agent-Based Simulation

19.3.1 Social and Economic Systems

19.3.1.1 Financial Markets and Systems

Research on financial markets and systems has relatively a longer history in agent-based simulation and is often called agent-based computational finance (ACF). Major contributions are (i) the clarification of bubble and anti-bubble phenomena; (ii) reproduction of the actual financial time series ("stylized facts") which include fat-tailed return distribution with high peak, volatility clustering, long memory, and the relations between changes in prices and trading volume; (iii) relations between trading mechanism and liquidity such as continuous double auction vs. call market; (iv) the roles of restrictions to stabilize the market such as Tobin tax, circuit breaker system, tick size, and intervention; and (v) the calibration of investor behavior between fundamentalists and chartists. These earlier studies indicate that the market participants are bounded rational and heterogeneous and that no systems seem perfect. In line with the trend in financial systems, students have grappled with the concerning issues.

Yoshiki Kano's research questions are how often investors refer to the stock prices and how the ratio of fundamentalists varies in accordance with the fluctuations of stock prices (Kano and Terano 2006, 2007). Kano developed his agent-based computational finance models for each of the research questions independently. To estimate the frequency of referring to the stock prices, he posed three assumptions: First, investor agents see the stock prices at regular but different intervals because this process may be costly. Second, investor agents know the market trend from only the current stock price and that which they lastly checked, which is possible to express the differences of the view to the market. Third, the model incorporates the "house money effect" by which investors with losses are more sensitive to the risk. On the other hand, to estimate the ratio of trading styles, fundamentalists, and chartists, he employed the so-called inverse simulation technique by using genetic algorithm.

Each of his computational experiments has the following findings: with respect to the referring timing, (1) the reference interval is linearly related to the autocorrelation of return series, by which the accurate reference interval is successfully estimated; (3) it is effective to select stocks from the prices on the estimated reference timing; (4) the relation between the discrepancy of the referred stock prices among investor agents and the movements of the prices afterward is consistent with "divergence of opinion model" by Miller (1977) and Harrison and Kreps (1978); and (5) the more the subjective profit for investors is, the less the performance of the prices afterward may be. On the other hand, with respect to the ratio of trading styles, (1) there is a negative relation between the ratio of fundamentalists and the stock returns, and (2) the proposed approach pertinently reproduced the price fluctuations in out-of-sample periods.

As the algorithm trading or high-frequency trading is becoming popular and equity markets have become a decentralized electronic network, new kinds of market institutions play an important role, and trading strategies need to be adapted. Yibing Xiong tried to solve these two contemporary research questions: relations between the usage of dark pool and market liquidity, and the performance of market making strategies in high frequency trading (Xiong et al. 2015a,b).

He firstly examined the relationship between dark pool usage and individual trading performance, which includes price slippage and order execution rate. Here, price slippage is about volume weighted average price, i.e., VWAP. For this purpose, his agent-based computational finance model is an order-driven stock market with two kinds of liquidity traders, low-frequency traders and high-frequency traders. Low-frequency traders, on the one hand, combine two kinds of strategies, fundamentalists and chartists, for their trading. High-frequency traders, on the other hand, predict the asset price from only the movement of past prices and submit both buy and sell orders. Therefore, their usage of dark pool is different from their types. His computational experiments confirmed that higher usage of dark pool led to higher price improvement only in case of mid-level of market volatility and that order execution rate decreased when market volatility increased and there were more dark pool usage. Then he compared between different market-making strategies of high-frequency traders and observed that market makers earned more return when they made use of offering prices based on the latest trading price and using the information about market volatility and order imbalance. He additionally examined scenarios where there were more competitors or where there was less latency to see how these factors change the performance of market-making strategies.

The financial crisis of 2008 much affected real economy as well as financial systems, which has been probably caused by (i) linkages between behaviors of financial institutions and asset prices, (ii) propagation of impacts through various transaction channels, and (iii) simultaneous deterioration of financial conditions caused by common exposure. To deal with such a crisis, tightening of regulation on financial institutions and strengthening of the role of central banks are considered. But, since it is not clear whether and to what extend these regulations are effective or have risks, analyses of their impacts on behaviors of financial institutions and inter-bank networks should be required.

Takamasa Kikuchi analyzed the influences of the financial regulation on financial institutions and the policies of central bank on the stability of the financial system by agent-based approach (Kikuchi et al. 2016a,b). For the abovementioned objectives, he posed on the following research questions: (i) whether a chain of failures in major financial institutions arises due to price decline of marketable assets; (ii) whether the risk, namely, the number of failures, is reduced by financial regulation; and (iii) to which such risks are passed on by the financial policies. His approach expands a failure propagation model by May and Arinaminpathy (2010) that incorporates price shocks to common assets. The simulation model expresses changes in the financial and credential conditions of financial institutions in response to those in asset prices and decision-makings for their investment and funding. It also includes the alternative issue on the fund balance provided by the central banks. By doing so, the simulation model explicitly represents the collapse caused by liquidity and deals with financial regulations and central bank policy. The main findings are as follows: First, a chain of failures through changes in the financial and credit situation of financial institutions caused by price fluctuations of marketable assets may arise. Second, some combination of financial regulations may increase the possibility of bankruptcy of individual financial institutions. Third, the central bank's policies may produce different risks from those mentioned in earlier studies.

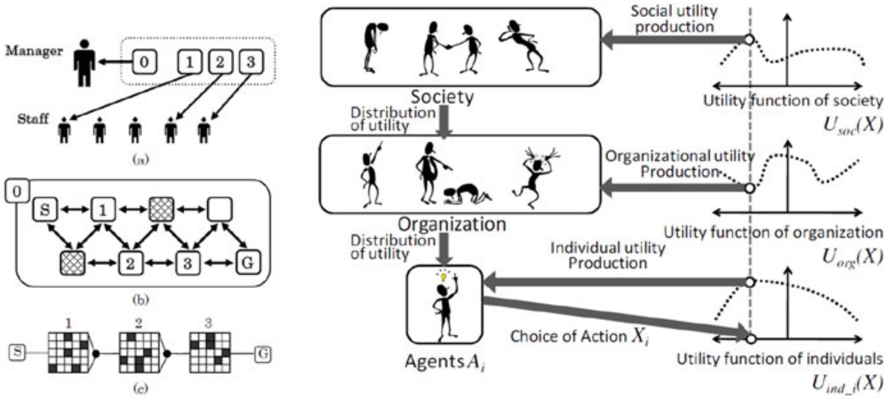
19.3.1.2 Organizational Behavior

Organizations such as firms and governments have their own purposes, and the members there try to do their best to accomplish these. Members are heterogeneous and have their own likes and dislikes. Leaders in the organization have to appropriately allocate the tasks to their subordinates or motivate them. Or, information needs to be transmitted and shared without any misunderstanding. Moreover, collaborative tasks across different sections or occasional changes in personnel may be required. Agent-based computational approach is an effective way to analyze such dynamics and to test the possible policy. In addition, since Terano lab has many working students, it is much easier to progress this project.

Yukinao Kenjo computationally represented and analyzed team behavior in cooperative organizations. He focused attention on both the roles of manages and the initiatives of staffs (Kenjo et al. 2009). For this purpose, his simulation model deals with the task processing of active members of the hierarchical organization using the maze problem-solving of reinforcement learning agents. The left panel of Fig. 19.1 shows the flow of task generation to partial task/unit task division in detail and goes on to explain maze problem learning, reporting to superiors, and task completion. In addition, the agents have two parameters, indifference index and identification index. Indifference index is an indication of compliance with orders from superiors. And identification index is an indication of the extent of identification of the member's purpose and values against that of the organization. These computational experiments show that a high performer in the organization within a given environment is not always so when she/he is placed in a different environment.

Takamasa Kikuchi presents another agent-based model of organization to analyze the relations between organization structure and personnel reshuffle, which is expected to show optimum possible performances against business environmental changes (Toriyama et al. 2009). The model focuses on the process of how the organizational recognition on business environment propagates when its members face new one. The model is a natural extension of the tag model of cultural assimilation by Axelrod. Using this model, he has found an optimal structure and personnel selection through random search and evolutionary computation techniques.

Satoshi Takahashi presents an agent-based simulation model to analyze performance of organization with heterogeneous members (Takahashi et al. 2013b).



Yukinao Kenjo's model Tomomi Kobayashi's model

Fig. 19.1 A snapshot of the agent-based models of organizations

A hierarchical landscape model with organizational and personal landscapes is proposed, and it puts difference of skills and values into difference of personal landscapes. The use of this model shows that an organization needs to have a certain amount of diverse members to improve the whole organizational utility under the changing environment. This is because while the uniform members stay at a state with higher individual utility even if there are diverse members in the organization, the diverse members discover a new state with higher organizational utility and then take others to that state.

Tomomi Kobayashi developed an agent-based model to unify the organizational "deviation" and "kaizen" activities (Kobayashi et al. 2012). Both of the activities are often supposed to break standards in operations within business firms, but they are different because kaizen increases both organizational and social utilities while deviation increases only organizational utility but decreases social one. Based on this definition, he created a simulation model based on NK model as well as Satoshi Takahashi and analyzed the conditions under which deviation and kaizen happen and the behavioral changes of members (Right panel of Fig. 19.1. His computational experiments show that the three factors, utility landscape, diversity of agents, and the reward system, affected the emergence of deviation and kaizen. Besides, real phenomena such as kaizen activities in Toyota are reproduced with an appropriate set of parameters.

19.3.1.3 Network

The third application is social network. Economic agents do not always receive or take into consideration global information for their decision-making. Rather, they exchange information with their family, friends, and colleagues. For this reason, interaction among agents occurs only locally, and researchers need to pay attention to its mechanism. Agent-based simulation can explicitly represent such interactions. In addition, as will be presented in the sequel, Terano lab has proposed an extended network model, "doubly structural network model," which enables us to deal with not only social interactions but also connections between something else such as goods or concepts.

Shinako Matsuyama empirically analyzed and computationally reproduced the mechanism of peer-to-peer communications in two ways (Matsuyama and Terano 2007, 2008).

The first study conducted questionnaire study, developed a simulation model, and pursued computational experiments to deal with how information, which is called "contents," by "word-of-mouth" communication is spread and shared among people. In questionnaire study, what kind of information such as news, fashion, music, comic, or so on is exchanged and how many pieces of information are exchanged in a single day were asked, and the subjects were business persons and students. She found that the contents were classified by the criterion, popularity, and that popular contents were different from the subject group. Then she built a simulation model where agents make a decision of how many contents they are going to exchange and whom they communicate based on three rules, closeness, authority, and similarity. Moreover, contents had two parameters, how many agents would distribute them to others and how often they are exchanged. Computational experiments successfully reproduced the process of information flow and supported her empirical findings. In addition, the results were dependent on the social network structure.

Likewise, the second study was on the information exchange dynamics in a firm. Here she analyzed the Enron email data set and attempted to reveal the process of its collapse. This study is essentially different from the first one because it made use of real data. The results include (1) the distribution of degrees in the social network follows a power law; (2) the network has the distinctions of small network; and (3) persons with a large degree have a tendency to distribute more pieces of information, and the information is more various. Based on them, she implemented computational experiments using the similar model in the first study and represented the similar results.

Masato Kobayashi computationally applied "doubly structural network model" (DSN model), which was originally created by Kunigami et al. (2009, 2010), to emergence of money and mileage point system (Kobayashi et al. 2008, 2009). DSN model consists of two levels of networks: the one of inner-agent model to represent their beliefs or knowledge about the world and the other of interagent model to represent a social network among agents[2] (Fig. 19.2). The mechanism of exchange in DSN model is as follows: Two linked agents will exchange two different goods with a probability if both of two recognize that these two goods are exchangeable. Upon learning and updating their belief, four processes, imitation, trim, conception,

[2]In this sense, Matsuyama's simulation model is consistent with DSN model.

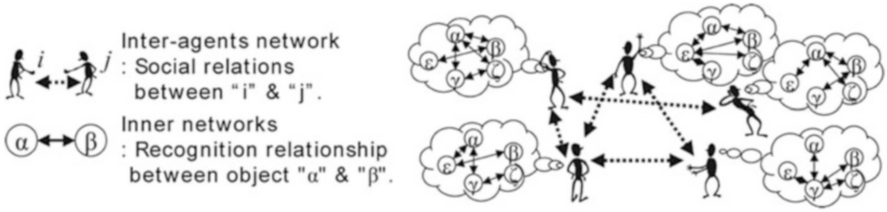


Fig. 19.2 A doubly structural network model

and forget, are incorporated. By doing so, some links are shared and others are forgotten. Using DSN model, Kobayashi and Kunigami have explained how the concepts of money as an exchangeable media emerge through agent interaction, respectively. On the one hand, Kunigami showed that (1) "the proto-money can emerge from commodities without distinctive properties"; (2) "the social network degree is a definitive factor for non-/single-/multiple-emergence of proto-money"; and (3) "the variance of the social network degree (existence of hub-agents) also affects emergence of proto-money." On the other hand, Kobayashi computationally analyzed the conditions under which proto-money emerges by changing the social network structure and its degree.

Jieliang Zhou investigated online media's management process using the word-of-mouth communication in social media by agent-based approach (Zhou et al. 2017). His simulation model deals with two competing online medias both of which explore and exploit an effective way of attracting customers in a social network. Here, the online media make use of two strategies in terms of the contents themselves, creating and selecting news article strategy and targeting strategy. The former strategy is such that a media agent tries to distribute similar contents which are considered as popular or to follow a popular content which its opponent has already distributed. The latter strategy determines to which customer agents the media agent would distribute contents. His numerical experiments observed that the trend-following strategy for the news article strategy and the degree strategy for the targeting strategy performed better. This indicates that rip-off contents, which are considered as the easiest to make profits for the medias, have increased dramatically these days.

19.3.1.4 Movement of People

The fourth application is movement of people in a space. Each person walks or wanders because she/he wants to arrive at a place or to find something. Or, she/he rushes to an exit in case of emergency. Observing and reproducing their behavior will help grasp what are the obstacles, how the layout should be made, and how the staffs should guide them when necessary. Students in Terano lab have studied such dynamics in a retail store and in a train station.

Ariyuki Kishimoto built "Agent-Based In-Store Simulator (ABISS)" to analyze how customers in a retail store walk around and propose an effective way to increase sales (Terano et al. 2009). For this purpose, firstly he conducted field research and analyzed the real sales data. The main empirical findings are that many of the customers spend about 20 min and buy vegetables, fish, and meats and that they are likely to come just before the lunch time and the supper time. Based on them, he developed the simulator to test the validity of sales promotions, and especially we investigate the effects of store design and arrangement of in-store advertisement and recommendation system. The computational experiments show that the flow of customers, which is related to the sales, depends on the design of a store and that the places of in-store advertisement and recommendation system vary their sales.

Masaki Kitazawa succeeded Kishimoto's pioneered work to better express the combination of movements and purchases of customers (Kitazawa et al. 2013). To accomplish this, he collected their walking flow data by using radio-frequency identification tag system equipped with both in market carts and shopping places and found that the behaviors of customers were classified into three patterns: walk all the way around in the store only once (83.3%), twice (15.3%), and three times or more (1.4%). Then he developed an improved simulator "ABISS-2nd" where those empirical findings were incorporated. His simulation study confirmed that it was necessary to take into account the stop ratio at every spot in the store so that the model reproduces both movements and what the customers purchase.

Toshiki Fujino specified Kitazawa's empirical finding in greater details to improve the explanatory power of the simulation model (Fujino et al. 2014). To overcome the issues of earlier works, he classified the customers into two criteria, the walking distance in a single visit and the number of items purchased, and then found that there are three walking patterns: (1) customers who buy only items except for vegetables, fish, or meats; (2) customers who buy only vegetables, fish, or meats; and (3) customers who buy vegetables, fish, or meats with other items. The first type goes toward the objective sales situation and does not walk a lot; meanwhile, the third one both walks all the way around in the store and visits the other sales situation.

Although this research project is still underway and has lots of things to do, these studies have been meaningful in that the customers are proved to be heterogeneous and some of the sales promotion policies are considered effective.

On the other hand, Kazuki Satoh analyzed the evacuation behavior in a train station (Satoh et al. 2009). When an emergency situation happens, passengers may have difficulty in being safe because they do not know the structure where they are and sometimes there is a lack of emergency exits. However, an intensive evacuation drill costs and spends a lot. Therefore, simulation study is required to grasp the behavior of people in case of emergency and to establish the way to evacuate safely. To solve this problem, he proposes an agent-based evacuation simulation model to explore issues and improvement ideas when passengers face emergency situations at a subway station. For this purpose, first he classified passengers into three types, emergency escape type, double back type, and follower type, and took up an actual station as a simulation space. Then he implemented computer simulations with respect to the influences of fire or damage of exits and the roles of guides. The main results are as follows: First, sheltering at the nearest exit is not always the most suitable action. Second, escaping for the second nearest exit usually shortens the refuge time. Third, to avoid stay, the guides should regulate the flow of traffic around the ticket gates and the exits.

19.3.1.5 Educational Systems

The final application is educational systems. In Japan, several educational policies have been proposed and introduced such as small-group teaching, teacher licensing system, school choice, and consistency in public education from middle school through high school. As well known, it is almost impossible to introduce two different educational systems at the same time for a comparative purpose. For this reason, computational approach may help better understand the pros and cons of each system. Indeed, before Prof. Terano started to work at Tokyo Tech, Atsuko Arai examined whether "education with breathing space" system was effective to the academic abilities of all students and found that educational policy lessened their academic abilities and widened the gap between top-ranked students and bottom-ranked ones. Since one of his visiting professors, Prof. Atsushi Yoshikawa, majors educational engineering, a couple of collaborative studies in this field have been accomplished.

Atsuhiro Kanzawa developed an agent-based simulation model to see whether small-sized classes improve the academic ability of students which is based on the segregation model by Shelling (Yano et al. 2015). Each of student agents has his/her preference of how she/he studies in every time step: with teacher agents, with his/her friends, and by himself/herself. In addition, he assumed that the student agents would follow three kinds of learning models, informational approach model, learning by teaching model, and motivation for learning model, from learning theory in the literature. The extent to which student agents earned their academic abilities was based on the combination of his/her preference and the learning model. Then, he investigated how many teachers should be allocated to each school in order to improve academic abilities of students with respect to each learning model. His main findings are as follows: first, any staffing decreases the abilities of the top 10%. Second, in contrast, the increase of those of the bottom 10% may depend on the staffing, and it is in proportion to the number of teachers in elementary schools.

Katsuhiro Yano extended Kanzawa's work so that he made comparisons between two educational policies, teacher allocation and teacher retraining (Yano et al. 2017). By doing so, his simulation model is able to see which policy works better to improve academic skills of students. For this purpose, a similar agent-based simulation model with student agents and the teacher agents is proposed. The student agents are based on academic achievement model and learning theory, whereas the teacher agents have three parameters in terms of teaching skills. The main results are as follows: First, increase in experienced teachers is helpful for the students with low academic achievement. Second, teacher retraining policy improves academic achievement of the high-leveled students.

19.3.2 Foundations of Agent-Based Simulation

While agent-based simulation has explained phenomena observed in social and economic systems, agent-based simulation itself has been improved for years. For example, large-scale simulations and real-time data processing have been enabled with more computational abilities. Or, to obtain more realistic simulation results, one has to incorporate more parameters into his/her model, but, in turn, she/he has to explore a huge parameter scale to set/fix an appropriate parameter set. Likewise, guidelines such as ODD protocol have been proposed so that researchers other than model developers can understand and test their simulation models. Among these, Prof. Terano and one of his visiting professor, Prof. Dr. Gaku Yamamoto, grappled with them. Moreover, one of Prof. Terano's former students, Prof. Setsuya Kurahashi, developed a so-called "inverse simulation" technique to effectively explore a parameter space.

Yuya Murata dealt with the issues of real-time data aggregation (RDA) which need to be solved by taking care of two technical points: parallel processing and accessibility to the corresponding data (Murata et al. 2014a,b). The former point is such that distributed systems may have difficulty in processing when they receive unbalanced data. Meanwhile the latter point may be caused by the huge amount of data which increases the replication cost. To overcome these difficulties, he decentralized the load for each issue by identifying particular agents among dissynchronizing agents. More concretely, he implemented, of censor log mining system, a simple RDA, by agent technology, and examined its performance. Figure 19.3 depicts the configuration of agents on distributed servers. Each agent equips a handler to process messages between agents and exclusive data records. The agent asynchronously processes messages sent from application procedures. Then, he applied the technology to a marathon ranking system as an example and showed the effectiveness of the proposed protocol.

Chao Yang with Setsuya Kurahashi, Isao Ono, and Takao Terano has proposed a framework for agent-based simulations with vast parameter spaces (Yang et al. 2016). This is a grid-based simulation environment named Social Macro Scope (SOMAS), which helps explore the optimal parameter set within the given possible parameter space as well as implement parallel experiments. According to them, simulation studies are classified into three types: forward simulation, inverse simulation, and model selection. Forward simulation is such that after building a simulation model and the corresponding computer program, researchers pursue simulations by giving a set of parameters and doing sensitivity analysis. Inverse simulation is such that researchers use simulation technique to calibrate phenomena which they want to explain or reproduce from their simulation model. Hence, this type is thought as an optimization. Finally, model selection selects the necessary

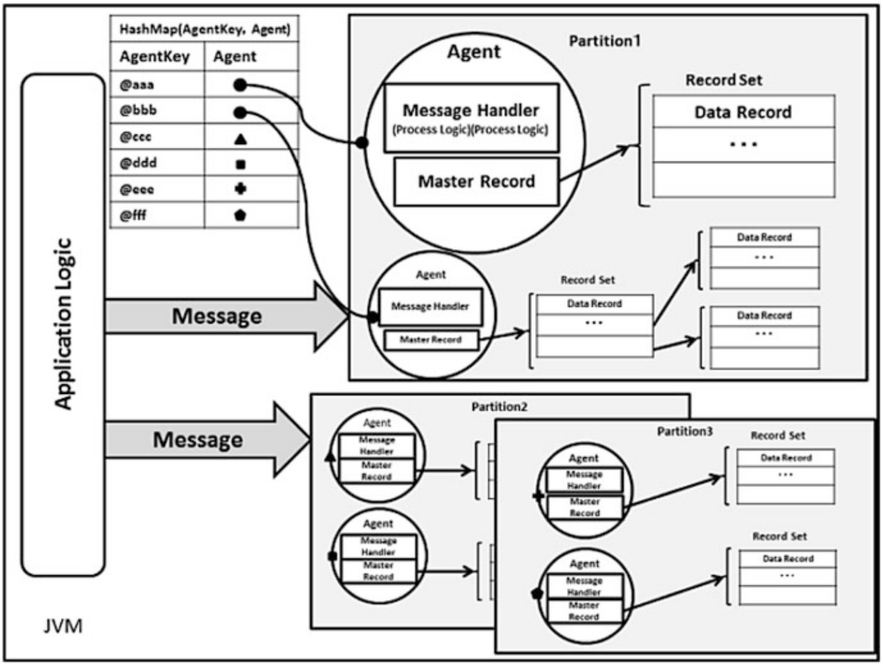


Fig. 19.3 Yuya Murata's real-time data aggregation model

parameters from the given parameter set and then explores the optimal value for the selected parameters. In this sense, model selection involves inverse simulation. Accordingly, SOMAS comprehensively deals with these three kinds of simulations. Yang et al. have applied it to their earlier study (Yang et al. 2009, 2012), family strategy analysis in cultural capital reproduction, and not only inverse simulation technique but also the model selection framework enabled them to discover a better parameter set to explain the conditions under which people succeeded civil service examination with much shorter computing time.

19.4 Concluding Remark

The works introduced here are just in social simulation literature, and many of them with other simulation works such as agent-based simulation of history and anthropology (Sakahira and Terano 2015, 2016) are in progress. In addition, as mentioned in Sect. 19.1, Prof. Terano contributed to evolutionary computation (Irvan et al. 2013), intelligent systems applied to service sciences (Chang et al. 2014) and urban systems (Sagai et al. 2011), elaboration and practice of learning theories (Hotta et al. 2010), business games (Koshiyama et al. 2011; Nakano and

Terano 2006, 2008), and augmented reality (Takahashi et al. 2010, 2013a), and part of them are introduced in this book. It is often said in sports that a good player is not always a good manager, and this may be applicable to any fields. However, every rule has exceptions. Prof. Dr. Takao Terano is a great researcher and a brilliant educator.

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