Agent-Based Modeling: Introduction and Perspective

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Abstract: Agent-Based Modeling (ABM) is a cutting-edge technique to understand various social phenomena. ABM is characterized by the points that: (1) computer simulation with software agents, which are equipped with internal states, decision rules, and information exchange mechanisms, (2) micro level interactions of agents, macro level emergent phenomena, and micro-macro links among them, and (3) new principles for design and analyses of social complex systems in the real world. However, the importance of the modeling methodology has not been common yet even in the academic societies. The paper discusses the principles, strength, and weakness of ABM. The paper also describes our recent research results. They include such social system task domains as behavioral finance, social interactions among group of people, emergence of money, and history simulation.
Key words: Agent-based modeling; Agent-based simulation; Social system analysis

1 Introduction

Recent progress of computer technology makes it possible to analyze social and economic systems via simulation studies. Among them, agent-based modeling is promising: we are able to make social sciences operational, communicable, and experimental. Agent-based modeling (ABM) or Agent-Based Simulation (ABS) is a new modeling paradigm [Axelrod 1997],[Epstein 2007]. 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.

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 [2004] 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. This requires adhering to the *KISS principle*, which stands for the army slogan *"keep it simple, stupid."*

Running an agent-based model is an easy task, however, the analysis is not [Terano 2007, 2008]. Even for a simple simulator with the KISS principle, we must cope with vast parameter space of the model. This paper discusses the problem regarding the parameter exploration of Agent-Based Simulation for social systems.

In ABM, 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. Robert Axelrod [1997a] emphasizes that the goal of agent-based modeling is to enrich our understanding of fundamental processes that may appear in a variety of applications. This requires adhering to the *KISS principle.* KISS stands for "Keep It Simple, Stupid!" It is a maxim that means: the simpler, the better, and is similar in notion the Occam's razor. Axelrod [Axelrod 1997]. In the book, he also considers the "Iterated Prisoner's Dilemma Game" as a good model to realize the KISS principle and states as follows:

This paper is structured as follows: The second section examines agent-based modeling and the KISS principle. The third section identifies requirements for simulation experiment to surpass the KISS principle. The forth section states how these requirements are reflected in the model, based on our study. The fifth section will give concluding remarks.

2 Agent-Based Modeling and the KISS Principle [Terano 2008]

Traditionally, study of society, economics and systems has approached the theory through cases, in which researchers examine well-structured documents with historical facts or approached mathematical

and/or statistical models with some numerical data. For example, financial theorist and engineers utilize concepts of probability and statistics. They often use tools from statistical physics for financial problems. In financial engineering, accordingly, the market is assumed to satisfy certain given conditions like physical laws in the natural world. However such assumptions usually do not hold. That is because the market is affected by decisions and actions of individuals who compose the market, and the trading rules on the market, unlike natural phenomena, are designed based on the decisions of those contained in the market. On the other hand, study of agent simulation, or more generally agent-based modeling, takes advantage of recent advances in computer's processing power, and shifts the focus from global phenomena to individuals in the model and tries to observes how individuals with their individual characteristics, or "agents" will behave as a group. Study on simulation methods in organizational systems has a long history. For example, the book written by Cyert and March [Cyert 1963] is a start point of organizational simulation. Among them, the garbage can model is well-known in organizational decision-making behavior [Cohen 1972]. The strength of the agent simulation approach 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. Axtell [Axtell 2000] suggested that agent simulation in social science could extend various aspects, which have been neglected in conventional theoretical studies. In agent simulation, 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. Though they cannot cope with computational complexity or combinatorial explosion in the simulation, agent base models are very effective to analyze complex social phenomena with simple description. We should switch our principles of conventional artificial intelligence approach, which tries to make agents smart, into ones to ravel "intelligence as a group" through agent-based modeling. Under such agent-based modeling principles, results of scientific study will be communicated in a form comprehensible to other researchers, and when it involves experiments, the results will be reproducible. Emphasis on the KISS principle in agent simulation is to truthfully respond to these two requirements. Needless to say, agent simulation is merely "understanding" and "execution" of a certain aspect of a phenomenon, but it has the potential to greatly advance the frontier of existing studies when it is used as a supplement to the theory or when theory is used as a supplement to it.

On the other hand, the simpler the model, the more explanatory interpretation of the result is necessary, in order to avoid easy explanation such as "We did it and we got it," as Izumi mentioned. Actually, several extreme explanations were given to the models discussed in Axelrod [Axelrod 1997a] and Epstein [Epstein 1996]. When the model is simple, the result seems to be obvious, and the harder we try to understand phenomena, the more complex the model becomes, which goes against the KISS principle.

3 What We Find from Agent-Based Simulation

3.1 Agent simulation of behavioral finance

Understanding the mechanism of the financial market is important to analyze rapid development of e-commerce and the robustness of the economic system. So far, however, such analyses have mostly used macroscopic mathematical models. Conventional financial models are analytical and require 'rationality' in the market and individual behaviors. The assumptions of rationality of conventional theories are summarized as follows: (i) that the market is effective and the information will be known to agents immediately and completely, (ii) that agents are capable of decision making that maximizes their utility functions, and (iii) that there is no limitation in the agent's financial resources, and transaction of any scale is possible. These assumptions are not met in reality, but they are inexplicitly assumed in designing, for example, financial products.

Based on the background, we have developed an agent-based simulation model to evaluate financial market behavior (Figure.1)[Takahashi, 2003, 2010, 2011]. We paid attention to the gap between the GARCH (Generalized Autoregressive Conditional Hetero-scedasticity) model and prospect theory in social psychology, and have examined the influence of the agent's risk management methods on the financial market [Takahashi 2003]. Here the GARCH model is a model to explain macro-level phenomena, which presumes the volatility (price dispersion) in financial engineering. On the other hand, the prospect theory is a micro-level model, which explains the nature of human decision making in cognitive psychology, which explains that the loss is estimated as larger than in actual fact. These

theories are well-known in finance and cognitive psychology, respectively, and can be combined by the agent-based model to enable macro-level analysis based on micro-level behavior.

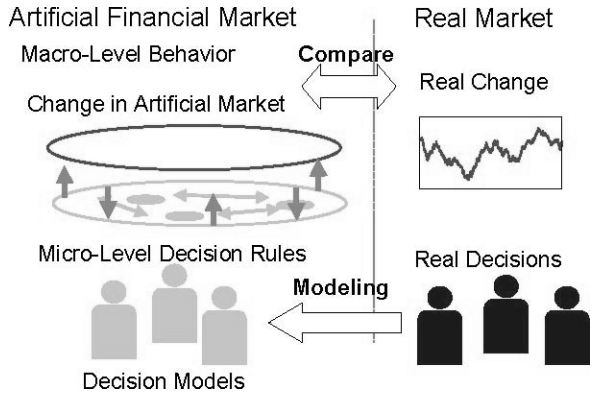

Figure 1 Agent Model for the Financial Market

In our model, we implemented a virtual market composed of four types of (rational and irrational) investors, which is also equipped with two types of risk management methods, VaR (Value at Risk) and portfolio insurance. The market we have developed consists of one thousand investors and allows them to trade two types of assets: a stock and a risk-free asset. In this market, multiple types of investors exist and conduct transactions based on the investment rules defined for each type. The market operations contain the following three steps: accrual of the corporate profit, formation of the investors' predictions, and determination of the traded price. In the following, we explain in detail, about the trading assets, decision rules of both active and passive investors, and decision procedures of market prices.

Findings from the experiment results are summarized in the following five points: (1) Even when there are a certain number of rational decision making agents in the model, the effective market assumption does not hold; (2) Even when there are rational decision making agents, irrational decision making agents will survive; (3) Behavior of agents with the mental model based on the prospect theory will determine volatility prospect based on the GARCH model. (4) Risk management methods in financial engineering are useful for individual agents. (5) However, in some cases, e.g. when excessive risk management is conducted or when there are investors who care about others, risk management may have a negative influence on the market. These results suggest that irrational investors incessantly have an impact on the price in the actual market as well, and further, indicate the effectiveness of applying agent simulation to the field of finance.

Our model is validated based on the following points: For requirement (1) a typical model in financial engineering and cognitive science is employed for an agent's micro-level decision making, and well-known results in the literature are employed for the market. Therefore, the results were conforming to existing theories within the range of 'rationality' on the macro-level. For requirement (2), relaxation of the 'rationality' assumption regarding agents, widens the gap between existing theories and at the same time gave no results conforming to actual data on the macro-level.

3.2 Agent simulation of social interaction

We have been working on an artificial society simulator TRURL, which aims to explore social interaction problems observed in such real-world activities as e-mail-oriented organizations and electronic commerce markets. We used this simulator to (i) analyze the emergence of leadership and conforming behavior in the electronic community, as well as (ii) analyze the stabilization and breakdown of distribution rules of information resources, which is the foundation to maintain the community [Kurahashi 2001].

TRURL is an artificial society model composed of agents with decision making functions based on the multi-attribute attitude model. This society is characterized by physical distance between agents, confidence distance, and communication attitude, and has a parameter space of the 13th power of 10 to the 15th power of 10. The agent has event-action rules and acts consuming the parameter called "participation motivation" (equivalent to the amount of energy or metabolism) during simulation. Furthermore, exchange of "knowledge" changes the agent's decision making structure and motivation value.

Decisions of the agents are made based on each agent's knowledge, but independent of this, there is a message exchange process among agents. Each agent interacts with other agents at discrete time steps according to the restrictions set for each simulation model. The interaction is performed according to knowledge attribute. When an agent receives unknown knowledge, it will accept it as is. However, when known knowledge is received, the nature of knowledge will change based on the following attunement behavior rules in accordance with its attribute.

With agent parameters set on the micro-level, the conditions of the society can be measured by macro-level information or social indices such as the speed of change in general social opinion, mal distribution of information goods measured by the Gini index, and the topological scale of the communication network.

In TRURL, the social index is optimized by Genetic Algorithms. That is, many parameters in the artificial society are adjusted by the evolutionary computation method. At this time, we will use the above social indices to evaluate the society as an objective function, and the resultant convergent society is analyzed from the characteristics of the agent group that composes the society. In the actual social system, these macro indices are measurable, but the system's individual agent characteristics cannot be obtained. On the other hand, in the artificial society, it is possible to create a society with the above-mentioned nature through "evolutionary computation" by using such macro-level measures as objective functions. Furthermore, we can obtain different knowledge by conducting simulation in the created society, and analyze the characteristics of the agents that compose the system based on parameter distribution information. The significance of simulation experiments of an artificial society lies in this point.

We call this method "inverse simulation," because it solves an inverse problem to identify agent parameter, and also "genetics-based validation," because it analyzes agent parameters created by genetic algorithms.

Agent simulation models using the artificial society model TRURL are validated based on the following. For requirements mentioned in (3) in the previous chapter, by systemically exploring a sufficiently large parameter space, it achieved the optimum value expressed by the objective function; in other words, it eliminates arbitrariness in parameter-tuning in design and execution of simulation. To address requirement (4), we statistically analyze a lot of individual information; that is, many simulation results to systemically perform sensitivity analysis of the simulation results.

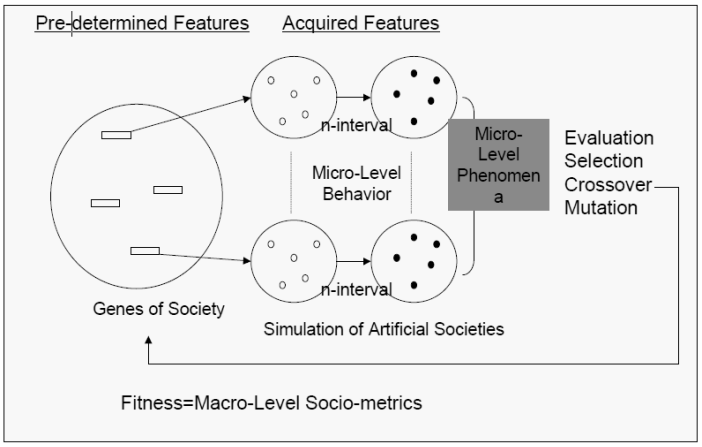

Figure 2 Evolution of the Artificial Society Through Inverse Simulation

3.3 Analyzing how the concept of money emerges

Money plays a unique role as a "medium for exchange" in economy and society, even though this has little practical advantage. This subsection presents a new social model on "the emergence of money from a barter economy". To describe the emergent phenomena, we have developed a new-type social network model, which consists of connected learning agents that have internal networks of recognition. The novelty of this model is the double structure of these heterogeneous layered networks i.e. the social network and inner networks. The double structure of this model enables us to describe dynamically that agents' interactions with learning represented explicitly via changing each agent's own inner network [Kunigami 2010].

The doubly structural network model of society is structured as in Figure 3.

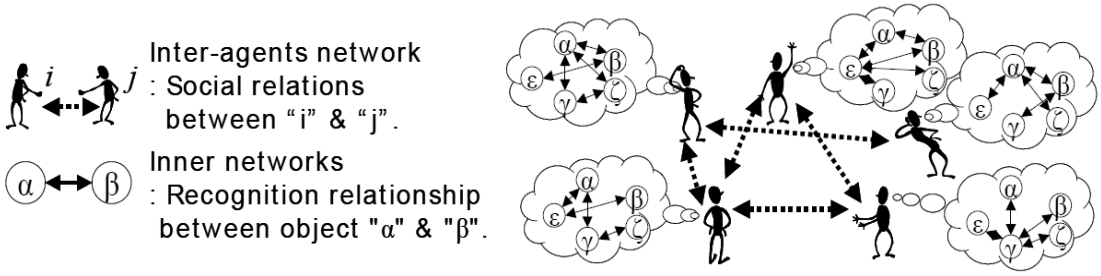

Figure 3 A Doubly Structural Network of Society

The model structure allows us the following advantages;

1. To directly describe the personal recognition of each internal network by shape.
2. To define autonomous evolution into the internal networks.
3. To describe the micro/macro interaction among agents with these inner evolutions.

DSN model is a conceptual one without a particular social learning / propagation mechanism, so we need to implement specific inter-agents and inner-agents' interaction for "the emergence of money". Among possible stages for the emergence of money, we have focused on the emergence of proto-money in which a certain commodity achieves "general acceptability" in the society. In our doubly structural network model, the emergence of proto-money α is represented as a self-organizing process in which a large population of inner-networks becomes similar star-shaped networks with a common hub α (Figure 4).

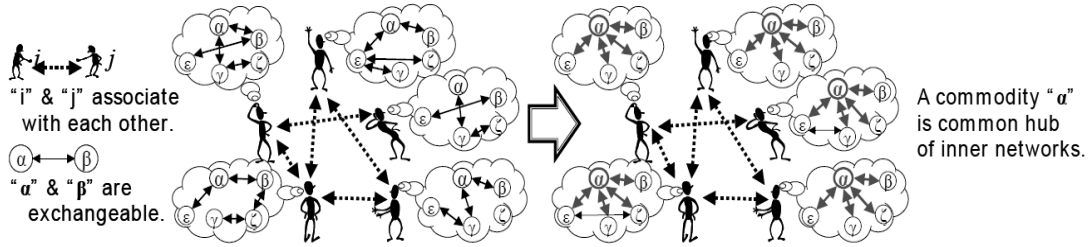

Figure 4 Emergence of Proto-money: Common Hub among Agents Represents General Acceptability

Using DSN model, we have implemented the “emergence of money” simulator [Kobayashi 2009]. Here we show simulation experiments of the emergence of money by the agent-based model without mean-field approximation. The first simulation demonstrates two analytical results from the previous section i.e. "proto money can emerge even from homogeneous commodities", and "no-emergence or single/multiple emergence of the proto-money depends on the degree of social network k". Changing the degree "k" of the regular-social network (250 agents), we conduct the simulation 200 times, and observe the ratio of the number of emergence of proto-money from 32 homogeneous commodities.

Figure 5 shows one of the experimental results. The horizontal axis and the vertical axis express the network degree and the ratio of the number of each emerged proto-money. In Figure 5, when the social network degree is small, no proto-money emerges. Hoowever, with increasing s social networkk degree, sinngle-emergencce and multipple-emergencee become domiinant in turn.

3.4 Rewinding history through Agent-Based Modeling

ABM is able to be applied to rewinding hidden historical events [Kurahashi 2008], [Yang 2008]. The target domain is the analysis of the civil servant examination system in China. The term “civil service examination” in historical science means the very tough examination for government officials of higher classes in China. The examination system has run for about 1,300 years. In our research, in this study, we investigate what would happen in a Chinese historical family line. We have analyzed a particular family line which had a great many candidates who passed the very tough examinations for Chinese government officials over 500 years.

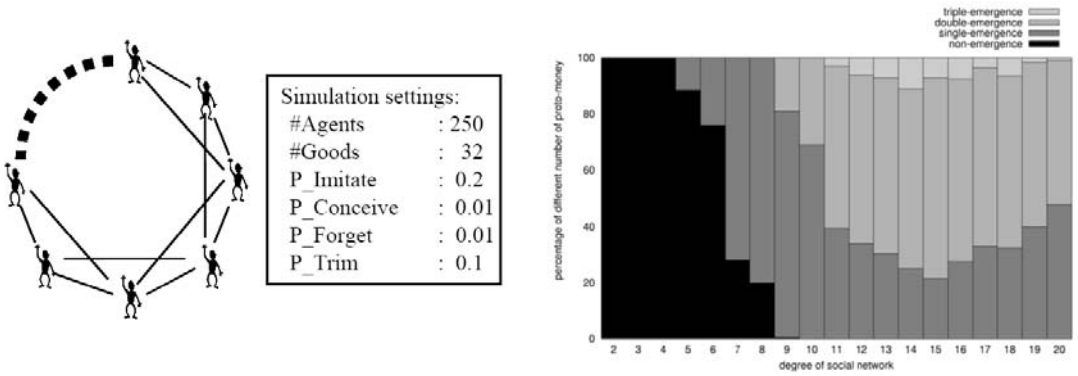

Figure 5 Thee Simulation on a Regular Social Network Illustrates that the Network Degree *k* (Horrizontal axis) Determines Thee Percentage off the Emerged Proto-money (non: Black, Single: Dark Gray, Double: Gray, More: White)

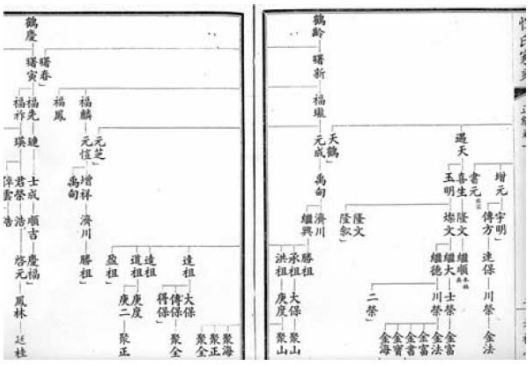

Figure 6 Photograph of Zupu

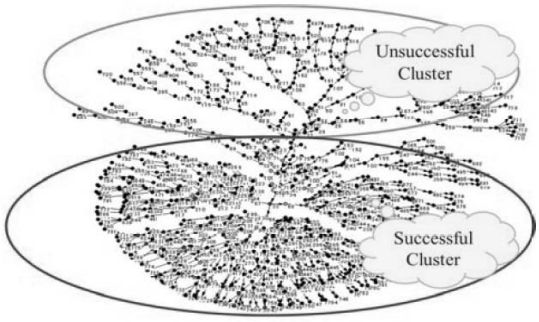

Figure 7 Sample Family Tree

From the intensive experiments, we have found that both grandfather and mother have a profound impact within a family in (1) transmitting cultural capital to the children, and (2) maintaining the norm system of the family. We conclude that advanced agent-based models are able to contribute to the discovery of new knowledge in the fields of historical science (Figure 8).

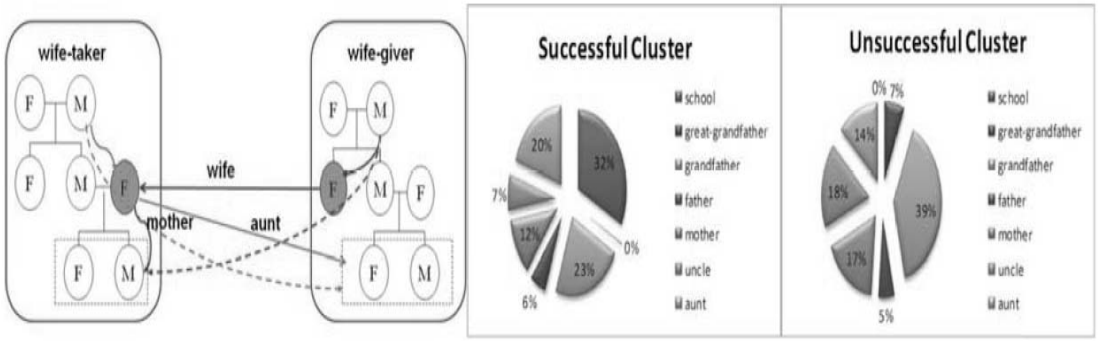

Figure 8 Roles of Females and Analysis of Successful and Unsuccessful Clusters

4 Concluding Remarks

In this paper, I have discussed the principle of agent-based modeling and our recent research results. The agent simulation method is very powerful as it can produce results without unnatural assumptions, unlike conventional approaches. For this reason, it is also gradually attracting much attention in thee field of social science, which has little connection with artificial intelligence study. Furthermore, many simulation tool kits have been released in recent years. On the other hand, there has been little persuasive discussion in the traditional social science field, due to beliefs such as that it ignores

conventional research hypotheses, or that the basis of the model is too weak to overcome the discussions in the literature. However, agent-based modeling is a very effective approach when considered as the third study method that interpolates the case study approach and mathematical approach.

References

[1] Axelrod R. The Complexity of Cooperation: Agent-Based Models of Competition and Collaboration[M]. Princeton University Press, 1997

[2] Axtell R. Why Agents? On the Varied Motivation for Agent-Computing in the Social Sciences[R]. Brookings Institution CSED Technical Report No. 17, November, 2000

[3] Cohen M. D., March J. G., Olsen J. P. A Garbage Can Model of Organizational Choice[J]. Administrative Science Quarterly, 1972(17): 1-25

[4] Cyert R. M., March J. G. A Behavioral Theory of the Firm[M]. Prentice-Hall, 1963

[5] Joshua M. Epstein: Generative Social Science: Studies in Agent-Based Computational Modeling[M]. Princeton University Press, 2007

[6] Masato Kobayashi, Masaaki Kunigami, Saatoru Yamadera, Takashi Yamada, Takao Terano. Simulation Modeling of Emergence-of-Money Phenomenon by Doubly Structural Networrk[C]. In K. Nakamatsu, et al.,(eds.): Proc. 1st KES symposium on New Advances in Intelligent Decision Technologies (IDT 2009), Springer SCI 199, 2009: 585-594

[7] Masaaki Kunigami, Masato Kobayashi, Satoru Yamadera, Takashi Yamada, Takao Teraano. A Doubly Structural Network Model: Bifurcation Analysis on the Emergence of Money[J]. Evolutionary and Institutional Economics Review, 2010, 7(1): 65-85

[8] Setsuya Kurahashi, Takao Terano. Distribution Rule Model by Agent Simulation. Transaction of Institute of Electronics, Information and Communication Engineers D-I, Vol.J84-D-I No.8, 1454-1461, 2001.[Kurahashi 2008] Setsuya Kurahashi, Takao Terano: Historical Simulation: A Study of Civil Service Examinations, The Family Line and Cultural Capital in China. Advances in Complex Systems (ACS), 2008, 11(2): 187-198
<http://www.worldscinet.com/cgi-bin/>.

[9] Takahashi H., Terano T. Agent-Based Approach to Investors' Behavior and Asset Price Fluctuation in Financial Markets[J]. Journal of Artificial Societies and Social Simulation, 2003,6(3)

[10] Hiroshi Takahashi, Satoru Takahashi, Takao Terano. Analyzing the Influence of Fundamental Indexation on Financial Markets through Agent-Based Modeling[C]. Ernst A. & Kuh S. (Eds.) Proceedings of the 3rd World Congress on Social Simulation WCSS2010 (CD-ROM), 2001

[11] Hiroshi Takahashi, Satoru Takahashi, Takao Terano. Analyzing the Influence of Fundamental Indexing through Inverse Simulation Analysis[C]. Proc. SICE Annual Conference 2011, WeB06-04, pp. 514-515, 2011.[Terano 2007] Terano, T.: Exploring the Vast Parameter Space of Multi-Agent Based Simulation. in L. Antunes and K.Takadama (Eds.): Proc. MABS 2006, LNAI 4442, Springer, 2007:1-14

[12] Terano T. Beyond the KISS Principle for Agent-Based Social Simulation[J]. Journal of Socio-Informatics, 2008,1(2):175-187

[13] Chao Yang, Setsuya Kurahashi, Keiko Kurahashi, Isao Ono and Takao Terano. Agent-Based Simulation on Women's Role in a Family Line on Civil Service Examination in Chinese History. Journal of Artificial Societies and Social Simulation 2009,12(2)
<http://jasss.soc.surrey.ac.uk/12/2/5.html>