Chapter 11
Amalgamating Agent and Gaming Simulation to Understand Social-Technical Systems

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Abstract Agent simulation is a tool to know about a could-be world. Also, gaming simulation is a language to communicate the future. This chapter discusses a new approach to understand complex socio-technical systems through both concepts. We start basic features on complex and/or complicated socio-technical systems, which address both technical and social issues with human decision-making processes. Then, we explain the importance of new ways of system thinking with human-in-the-loop manners. For the purpose, we propose a methodology to amalgamate agent- and gaming simulation. The characteristics of the methodology are summarized as follows: (1) Systematic analyses on users' behaviors in gaming simulation; (2) Machine learning based log analyses methods about agent-simulation processes; (3) A formal description method applicable to both agent- and gaming simulation models; (4) The description of each process is grounded into a could-be case, which, in this paper, we mean a latent case induced by a simulation result and this can be utilized as a text of case method learning, and (5) Descriptions on practical application in socio-technical problems.

11.1 Introduction

As the scale and complexity of the Systems of Systems (SoS) and socio-technical systems becomes increasing, in order to design and implement SoSs, in conventional ways of thinking, their systems boundaries must be clearly defined. However, in today's world, we must assume that the boundaries are constantly shaking. On the other hand, the existing system theory and technology for these areas are still in their infancy. In this chapter, we discuss a new approach with agent simulation and

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gaming simulation in order to develop and practice new SoSs with both humans and machines in an open and ever-changing social environment. As Epstein (2007) describes, agent simulation is a tool to know about a could-be world. Also, as Duke (1974) mentions, gaming simulation is a language to communicate the future. We believe that the amalgamation of the two methods is indispensable.

One of the unique characteristics of our approach is that it is a human-in-the-loop type participatory methodology, which extends the concept of not only gaming simulation often used in design thinking and systems thinking workshops, but also agent simulation recently used to design and analyze complex socio-technical problems. In this approach, we systematically describe and analyze scenarios obtained from agent simulation results and evaluate their validity by gaming simulation with both human and computer players. Using the approach, thus, decision-makers involved in system development, operation, and use can understand system requirements and specifications in a dynamically changing environment.

This paper is mainly based on our recent work on agent simulation, gaming simulation, log analysis methods for agent simulations; formal methods of describing agent modeling; and practices related to application issues.

The remaining structure of this chapter is as follows: In Second section, we describe the difficulty of defining system boundaries in the implementation of a socio-technical system; In Third section, we explain unique features of the constructivist approach and agent-based simulation; In Fourth section, we summarize the significance of constructivist approach; Then in Fifth section, we introduce a formal description method to systematically understand both agent-simulation and gaming-simulation results; In Sixth section, we give a perspective on the integration of constructivist and participatory approaches; and finally in Seventh section, some concluding remarks follow.

11.2 Difficulty in Defining the Boundaries of a Socio-Technical System

SoSs including socio-technical systems are intrinsically co-evolutionary systems that emerge in an interdependent manner as a result of rapid technological advancement and social activities such as the roles and relationships among various kinds of technologies, individuals, and social and/or organizations changes. In other words, recent developments in communication, transportation, and distribution technologies have brought about significant changes in the interaction between individuals and organizations. Those changes are further accelerating technological changes by creating new demands and innovations. In addition, the large amount of aggregated and visualized information provided by information and communication technologies affects the decision-making process of individual actors as well as institutions involved in the planning and execution of economic and social policies. Thus, the coevolution mechanisms of SoSs definitely create and annihilate a variety of new micro-macro-links in our society. The accumulation of information through the emergence of new social agent behaviors makes possible new technological innovations. In this way, technology and society form the co-evolutionary system, then, the roles of technology and the roles of individual agents and organizations in our society also change in the process of coevolution.

In SoSs, it is difficult to define the boundaries of a system although the existence of the system boundary has been an obvious prerequisite for traditional system implementation with conventional systems thinking. When we look at this difficulty from the outside and inside of a system, we can see that not only the external environment of the system changes, but also the boundary between the environment and the system change due to the coevolution of the external environment and the system. On the other hand, within a system, the behavior of subsystems and individuals, or their connections, change during the process of mutual coevolution. In the interior of a system, not only the organization (roles of components) and structure (connections among components) can change, but also, the components themselves undergo aggregation and decomposition. Therefore, the boundaries and their properties change both within the system and among the system, subsystems, and individual components. In other words, in a socio-technical system, the boundaries are fluctuating both inside and outside of the system, and it is difficult to describe the system in a stable manner.

Fluctuations in the boundaries of socio-technical systems as co-evolutionary systems also change the relationship between the system and stakeholders, who would like to observe, describe, design, implement, and control it. This means that the invariance or constancy of the positions and assumptions of observation and control over the system cannot be assured. Not only that, but the positions and perspectives of various stakeholders on the system also change from external observing and controlling agents to internal decision-makers, or from inside to outside of the system, due to fluctuations in the boundary between the external and internal in socio-technical systems (Fig. 11.1).

This is one of the difficulties in defining the boundaries of a socio-technical system compared to a conventional engineering system. For example, aerospace

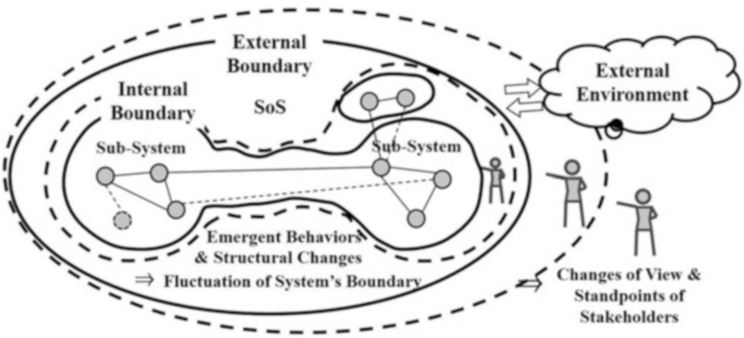

Fig. 11.1 Relation of the fluctuation of the boundary and the standpoints of stakeholders in a socio-technical system

systems and/or nuclear power generation systems are oriented toward rigid and stable systems, in which they try to guarantee the inherent stability of the internal system by strictly separating the subject and object of control. In contrast, the socio-technical system is a loose and inherently unstable system, in which the boundaries between interior and exterior and between subject and object are ever fluctuating.

11.3 Constructivist Approach and Agent-Based Simulation

The constructivism approach is effective to apply to socio-technical systems with fluctuating boundaries due to the coevolution mechanisms described so far. It is complementary to reductionism, which analyzes the necessary conditions for the existence of an object by breaking it down into its elements.

For the purpose, agent-based simulation (ABS), or agent simulation in short, a typical constructivist approach, is a good tool to elucidate social phenomena. Agent simulation treats the minimum components of a society as groups of individuals. ABS tries to model systems from the bottom-up using multiple actors called "agents," each with an internal state, decision-making and/or problem-solving capabilities, and communication ability, and then to analyze the resulting generative phenomenon and scenarios based on their interactions. ABS has several unique characteristics as follows.

1. At the micro-level, agents have individual internal states, and behave and adapt autonomously in their attempts to exchange information and solve problems.
2. Macro-level properties of the target system emerge from the collective actions of the agents.
3. Micro–macrolinks are created between agents and the surrounding environment, and the system state changes as they affect each other (Fig. 11.2) (Terano 2020).

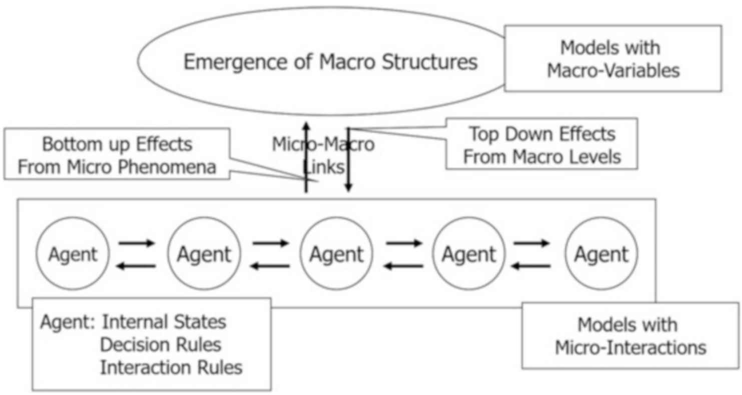

Fig. 11.2 Structure of agent-based simulation model (Terano 2020)

This approach is useful in analyzing macro-phenomena created by agent–agent interactions at the micro-level, as well as the phenomenon of micro–macro links whereby agents are subject to top-down effects. In this respect, ABS is applicable to the system of co-evolutionary interaction between technology and society, as we have described so far. For more information on this, please refer to previous commentaries (Terano 2020, 2021).

One of the examples to apply constructivist approach in our group is to reveal the conditions for the establishment and collapse of money concepts by means of a simulation model. The basic idea of the model comes from the historical observation that some goods have become common objects of exchange in a society (Yasutomi 1995; Kunigami et al. 2010). The model in Kunigami et al. (2010) is unique in the sense that, to represent the interaction of social learning on the social network, they use double structure of inter-agent social networks and inner-agent recognition networks. This double structure of networks enables us to describe and to analyze the emergence of common knowledge or organized/collective recognitions in the society. Doubly Structural Network Model handles social propagation of agents' knowledge and recognition such as exchangeability or acceptability of commodities. The structure of this model is illustrated in Fig. 11.3. The model allows us the following advantages.

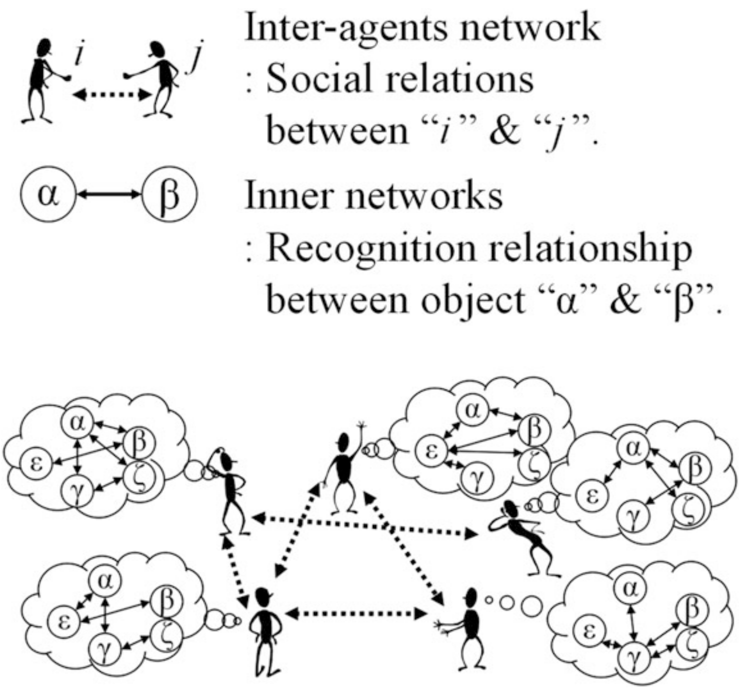

Fig. 11.3 A doubly structural network of a society to explain the emergence of money phenomena (Kunigami et al. 2010)

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.

However, the 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." ABS is one of the techniques to implement the model to derive interesting results on this important classical problem in economics.

Another example by Mukai et al. (Mukai and Terano 2018, 2019; Mukai 2019) is to study constitutive analyses of structural changes in subsystems in a rapidly changing external environment using agent simulations. Mukai et al. developed functions of an agent for the inter-business trading structure model, an inter-business trading structure model in which a group of firms spontaneously constructs and reorganizes their trading networks by changing production items and trading relationships in order to gain profits in a dynamically changing inter-firm trading environment. In the paper, Mukai et al. show that a transaction structure model that incorporates a decentralized structure with constraints on decentralized inter-firm transactions that allow firms to flexibly adapt to environmental changes explains the changes in actual transaction data in the Japanese software industry. Also, the boundaries from which the decentralized to centralized structure of its inter-firm transactions effectively arise are shaky even in the same domain of industry (Mukai and Terano 2018, 2019, Fig. 11.4).

Because of the above characteristics, ABS has the following implications for systems in which not only technology and society interact in a co-evolutionary manner, but also the boundaries in their internal structures are fluctuating. First,

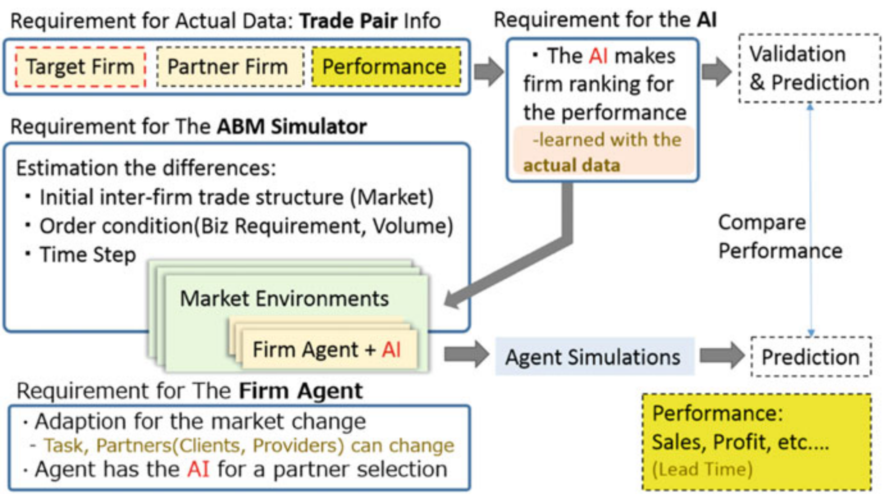

Fig. 11.4 Framework of inter-business trading structure model with ABS (Mukai 2019)

ABS enables us to observe changes in the social behavior of agents caused by changes in the boundary conditions of technology, such as the functional differentiation of agent groups and the creation and disappearance of hierarchies due to changes in the network structure. This makes it possible to realize the fluctuation of the internal boundaries of a social system as an emergent phenomenon of functional differentiation and network structure by agent simulation. Second, ABS allows us to observe bidirectional effects between technology and society, such as changes in the propagation and diffusion of new technologies because of the differences in social network structures and the emergence of new social network structures that follow them. Therefore, ABS is significant as a constructivist approach to techno-social systems.

11.4 The Significance of the Constructivist Approach

In co-evolutionary systems such as socio-technical systems, constructivist approach is indispensable. Co-evolutionary systems often show path-dependent structural and behavioral changes. This causes adaptive evolution of the system with the outside world and functional differentiation within the system, because of the shift of the boundary between the inside and the outside. The evolution and change of such systems cannot be predicted from the properties of the elements alone; therefore, a constructivist approach is necessary, adding to the conventional reductionism approach. In particular, for social phenomena where there are no first principles, various attempts have been made to extend ABS principles. These attempts include selecting adequate models to ensure objectivity and to apply evolutionary computation techniques to solve the inverse problem for data assimilation.

For example, Kurahashi (2018) proposes inference methods for agent model parameters and inverse simulation methods for verifying validity for socio-technical systems study. 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. Adjusting parameters can possibly create a predetermined result. While on the other hand, inverse simulation is executed based on the following procedure (Fig. 11.5).

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, we have developed inverse simulation method. Inverse simulation is able to adjust so many parameters necessary for agent simulation programs. We apply both the evolutionary computation and

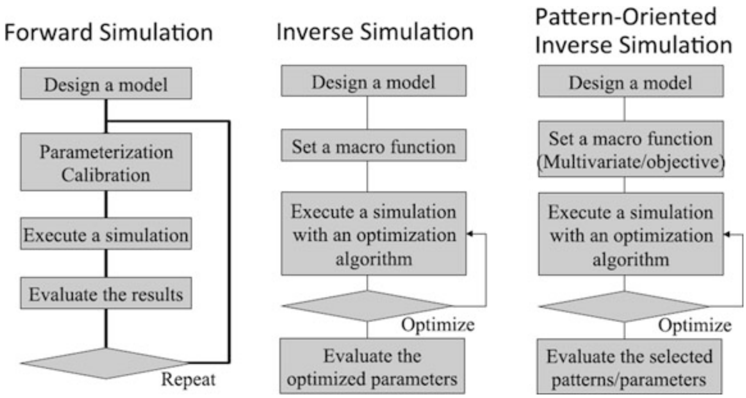

Fig. 11.5 Flows of forward simulation (left), inverse simulation (middle), pattern-oriented simulation (right) (Kurahashi 2018)

reinforcement learning techniques to inverse simulation, which can optimize functions with complicated and a large numbers of variables appeared in the simulation model. Please refer to the other articles for detail (Terano 2007; Mori and Kurahashi 2011; Yang et al. 2009, 2012).

In the following, we introduce new approaches to content analysis of agent simulations. We propose two methods for tracing agent decisions in a run of the simulations. The one focuses on agent decision-making in a run, and then analyzes the simulation log of each trial as a case. The other approach is to classify and to describe the various simulation logs as a set of possible outcomes, focusing on the overall structure of the agent simulation trials as the set of path-dependent outcomes. These two approaches, although still in development, are an important keystone of integration with the participatory approach via the case description methodology described below.

The first methodology for content analysis is Kobayashi's method of generating virtual cases from the logs of individual trials of agent simulations (Kobayashi et al. 2012). The summary of Kobayashi's method is as follows.

1. Simplify the agent simulation model and create a case design template based on the model.
2. Use it to generate a virtual case while checking the consistency of the simulation results.
3. Convert this virtual case into a realistic case (Fig. 11.6). By comparing with real business case, we can confirm the explanatory range of the model. In Fig. 11.6, a "could-be case" means a latent case induced by a simulation result.

This method allows us to evaluate the behavior of a complex system once abstracted from the agent simulation, and then ground it back into the case to improve the explanatory power of the simulation.

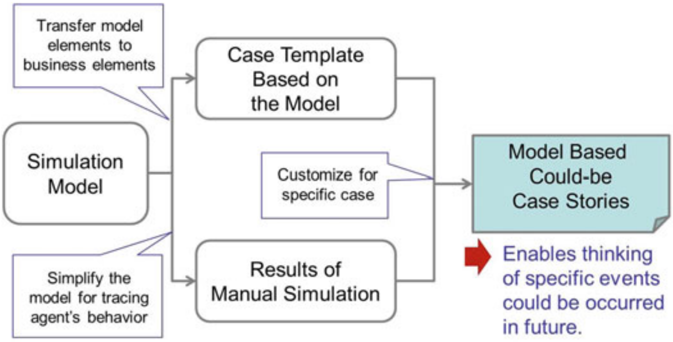

Fig. 11.6 Framework of could-be case generation through ABS (Kobayashi et al. 2012)

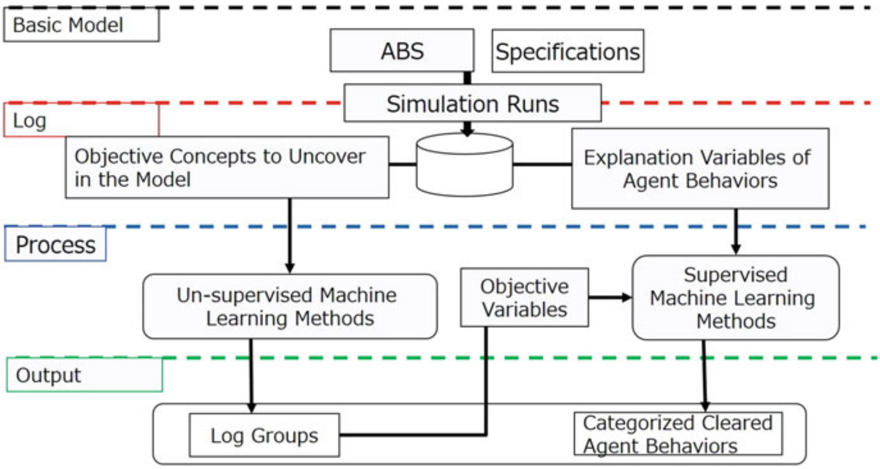

Fig. 11.7 Framework of classification of ABS logs (Tanaka et al. 2017)

The second methodology for content analysis of agent simulations is the method of classification of simulation results by Tanaka et al. (2017). This involves the following steps.

1. Decomposing the entire set of simulation logs into clusters according to the model structure.
2. Analyzing the decision-making processes in the central logs of the clusters compared to each other using machine learning methods, such as decision trees.
3. Allows known behavior of the simulation and understand the relationship between unknown behaviors as differences in the size and distance of clusters and decision-making involving each trial (Fig. 11.7).

11.5 Formal Description of the Results of Agent Simulation as Could-be Cases

In order to connect the two methods of content analysis of agent simulations and to bridge the gap to a participatory approach, we propose a new management decision description model (Managerial Decision-Making Description Model; MDDM). MDDM formally describes real business cases, virtual cases in Kobayashi's method, or virtual cases generated from logs that characterize clusters in Tanaka's method. Furthermore, MDDM is a visualization and inter-comparison tool for stakeholders of socio-technical systems to understand similarities and/or differences occurred in the system behaviors. Thus, this approach will play a role in linking the participatory approach, which will be discussed below, towards the integration of gaming simulation and cases, and the constructivist agent simulation and cases approach.

MDDM as a case description model has been proposed as a business case description model of innovation (Kunigami et al. 2019, 2020) and is being applied to the analysis of the results of agent simulations (Kikuchi et al. 2018, 2019). MDDM is able to represent business innovation processes as a decision scheme; that is, by linking changes in business structures (Objective-Resources Pairs) with changes in actor decision-making (Observation-Action Pairs). This allows us to formalize and express the changes in business structure due to decision-making within an organization (Fig. 11.8). The details of MDDM related discussions will be presented elsewhere.

This formal representation makes it possible to compare the structural differences between cases by drawing the MDDM diagram from the same point of view. On the other hand, while describing the same case from a different point of view, the

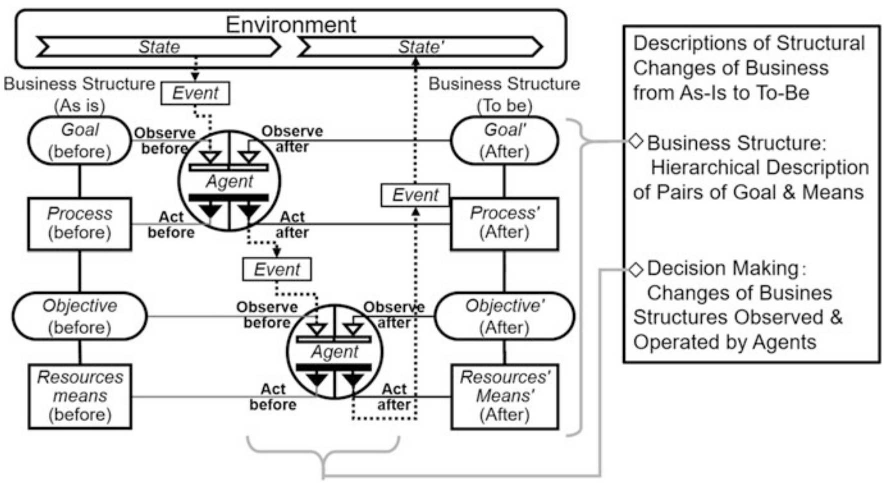

Fig. 11.8 Scheme of managerial decision-making description model (MDDM) (Kunigami et al. 2020)

diagram reflects the differences in understanding of the different perspectives. Kikuchi applies the MDDM scheme to the analysis of agent simulation logs by Tanaka. The paper reports a comparative study between virtual cases and real cases obtained from a cluster of organizational simulation logs.

11.6 The Importance of a Participatory Approach

In a co-evolutionary socio-technical system, the relationship between the positions and perspectives of stakeholders, including ourselves, and the system boundaries is no longer constant. The position/viewpoint of an observer/controller outside the system can also be transformed into an actor or a part of the system, and vice versa. As positions and perspectives on the system waver, the behavioral rules of stakeholders, such as objectives and constraints, also change in flux.

A participatory approach is necessary in the design and implementation of socio-technical systems in which the relationship between stakeholders and boundaries is fluctuating. The participatory approach refers to activities that promote understanding of both the behavior of the system and the actions of the participants through the participation of people who are potential stakeholders. Therefore, executing a human-in-a-loop social simulation or gaming simulation, both human players and computer agent players participate the simulation process at the same time. Below, we present two examples of participatory approaches: the first one is research the integration of constructivist approaches with similar business cases; and the second one is research to detect participant decision-making points in business gaming.

As novel participatory approach, Nakano and Terano (2004) proposed a case-based business gaming method by integrating real business cases and gaming simulations. First, they designed a gaming simulation system based on a real business case. The game models decision-making processes of top and middle management with the original case as the correct way of the play to the game. This enables the players as potential stakeholders to acquire perspectives as external observers and case describers in parallel, in addition to the different levels of decision-makers in various aspects of the internal context. Figure 11.9 depicts the framework of their integration method.

In a participatory business gaming context, Koshiyama et al. investigated the methods of measurement and evaluation of players' cognitions and judgments during business game playing (Koshiyama et al. 2008, 2011). They designed performance sheets to detect players' decisions during the game play. Using the performance sheet, they gathered log data of the game play game log in order to analyze the learning processes of a computer supported business game. Each player was asked to fill in the performance sheet about the information: how they perceive the target state, state variables, and control variables at each point in time and records their understanding of the changing structure of the problem from their point of view. The contents described in the performance sheet represent the same type of formalization of decision-making in the formal description of the case by MDDM.

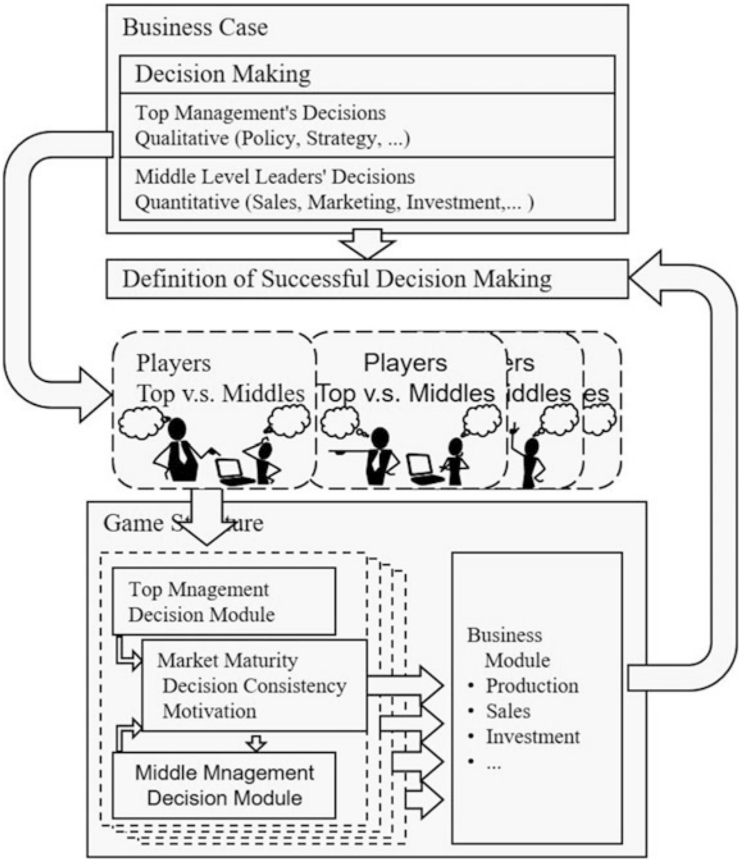

Fig. 11.9 Framework of case-based business gaming method

Therefore, based on the contents in the performance sheet, they are able to visualize players' cognition on decision-making in business gaming (Fig. 11.10).

11.7 Toward the Integration of Constructivist and Participatory Approaches

In this section, we discuss the integration of constructivist and participatory approaches. The analytical methods of agent simulation, a constructivist approach, and gaming simulation, a participatory approach, have one common feature in which they both use real and virtual cases.

As we have seen so far, in order to analyze the effects of emergent behavior and structural changes that alter the system boundaries, we are required agent simulation techniques from constructivist approach. In this process, the results of the simulation

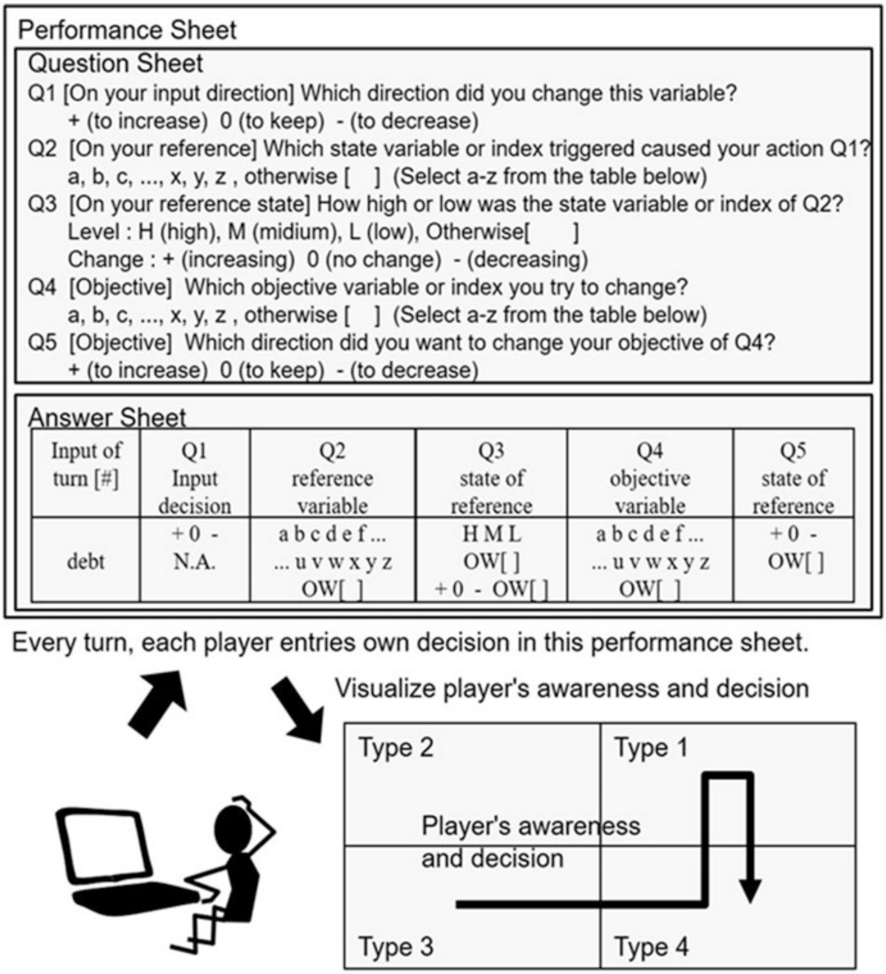

Fig. 11.10 Visualization method of players' cognition on decision-making in a business gaming

are categorized as a whole, and each categorized result should be formally described as a hypothetical case by a descriptive model. This allows us to not only ground the simulation results to the real case, but also to compare the unknown phenomena with the real or known cases.

On the other hand, participatory gaming simulation approach is necessary to analyze changes in the relationship between system boundaries and stakeholders' perspectives. The approach is also useful to promote stakeholders' understanding on targeted socio-technical systems. Such types of gaming simulation can be designed from various real or virtual cases describing specific relationships between the system and the stakeholders. We can also deal with the actions and understandings of the stakeholders who participated in this game through their decision-making and

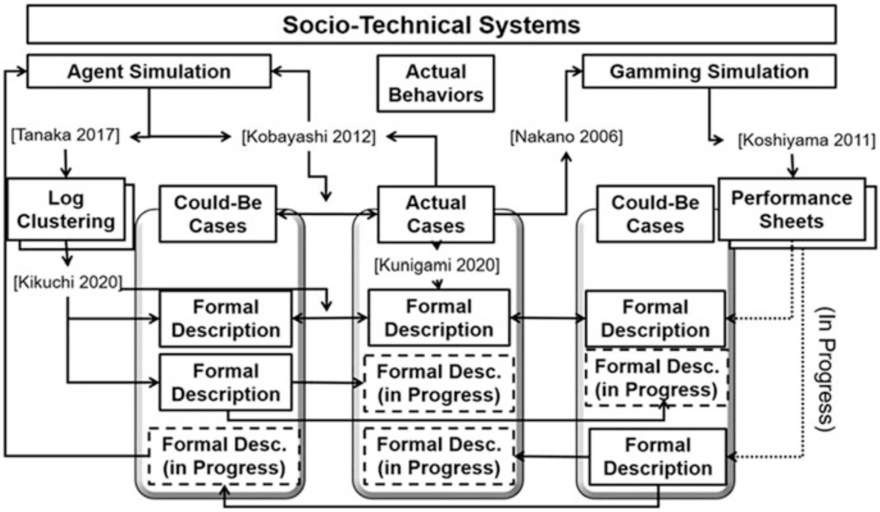

Fig. 11.11 Relationship between agent simulation and gaming simulation for understanding socio-technical systems

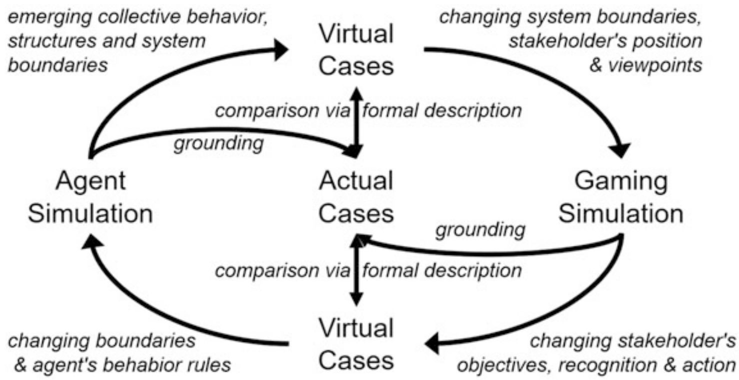

Fig. 11.12 Integration of agent- and gaming simulations with case method

their perspectives. The relationship between agent-based- and gaming simulation is summarized in Fig. 11.11.

Based on the discussion above, we can consider the following scenario for the integration of constitutive agent simulation and participatory gaming simulation (Fig. 11.12).

1. Extract and categorize fluctuations of system boundaries due to emergent behaviors and structural changes from agent simulation logs. We generate virtual cases from these types and compare them with real cases and ground them.

2. From the described hypothetical cases, we can generate gaming simulations that include changes in the participants' viewpoints and positions due to fluctuations of system boundaries.
3. From the play log of the gaming simulation, we can generate hypothetical cases, reflecting changes in stakeholder objectives, cognitions, and behaviors. Then, we can compare them with real cases and hypothetical cases generated from the agent simulation.
4. In the hypothetical cases generated from the gaming simulation, we can reflect future agent simulation systems about changes in system boundaries and stakeholders' decisions/interactions, which have not been realized in the current agent simulation.

The realization of such a scenario would yield the following new insights.

1. Reflect both explicit/potential behaviors and boundary fluctuations of socio-technical systems into novel system design and/or implementation.
2. Reflect the changing perspectives, objectives, and decisions of stakeholders in the operation of the system.
3. Promote stakeholders' understanding of and engagement with the socio-technical systems in which they are involved.

Our research to extend this scenario has been in progress on the side of the constructivist approach, inspired by the results of the participatory approach. Also, we are beginning to apply our results to the participatory approach. We believe that these new methodologies will evolve symbiotically across the boundaries of constructivist and participatory approaches. We would like to report on the results of these ongoing studies, which we have not been able to present in this paper, elsewhere.

11.8 Concluding Remarks

In this chapter, we have discussed the methodology to contribute the explicit/implicit behaviors and boundary fluctuations of socio-technical systems for novel system design and implementation principles. In addition, we have described ways to integrate stakeholders' changing perspectives, objectives, and decisions in order to promote understanding and engagement while reflecting their changing perspectives, objectives, and decisions. To work the proposed scenario, we must make progress on the side of the constructivist approach, taking cues from the results of the participatory approach and vice versa. In the future, we hope that these new methodologies will evolve as interactions to cross the boundaries of the existing strategies.

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