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Dynamics of rules internalized in dynamic cognitive agents playing a multi-game

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Abstract: Rules such as laws, institutions, and norms can be changed dynamically in our society, because they are shaped by interactions among social members who are affected by them. However, there are also some stable rules enhanced by interactions among rules. In this article, we discuss whether or not rules can be stabilized by interactions among the rules. To investigate this, we propose a multi-game model in which different games are played simultaneously by the dynamic cognitive agents. A minority game (MG) and an *n*-person iterated prisoners' dilemma game (NIPDG) are adopted. In our simulation, we found that the agents internalize the complex rules expressed as intricate geometrical shapes like strange attractors on the phase spaces, when the complex macro dynamics emerged. Furthermore, it showed that the macro dynamics shaped by the macro rules in the MG can be stabilized by interaction between the MG and the NIPDG rules internalized in the agents.

Keywords: Dynamic cognitive agent, Internal dynamics, Minority game (MG), Multi-game, N-person iterated prisoners' dilemma game (NIPDG), Simple recurrent network with self-influential connections (SRN-SIC)

1 INTRODUCTION

There are many behavioral guidelines that have an influence on determination of our actions in our society. Rules such as laws, institutions, and norms can be regarded as the guidelines. We focus here on the institutions as the rules. North[1] claims that the institutions establish stabilities of themselves by making complex aggregates of them. Many institutions mutually support each other, and their functions are enhanced by other institutions. Aoki[2] defines this enhancing effect as institutional complementarity.

On the other hand, Nishibe[3] proposes an institutional ecology. This institutional ecology is defined as a dynamical system in which many institutions can be shaped and fluctuated through changes of human cognitions and behaviors by interactions among the institutions. He claims that the institutional ecology becomes a complex system, and diversity of the institutions is maintained, because the interactions among them are nonlinear.

The purpose of this article is to discuss whether or not rules can be stabilized through interactions between the rules actually. According to North's interpretation[1], the institutions are distinguished between formal and informal institutions. We refer to the formal institutions as global rules and the informal institutions as local rules. In this study, we assume that the local rules are the global rules internalized in the individuals and play an important role to stabilize the global rules and the macro dynamics based on the global rules, because their actions are affected by each internalized rules, and the global rules are shaped by the actions of all individuals.

In order to investigate what effects the interactions between the local rules of the individuals have on the stabilization of the global rules and the macro dynamics, we propose a multi-game model in which different games are played simultaneously by the dynamic cognitive agents who can internalize the rules through the learning process.

2 MULTI-GAME AND DYNAMIC COGNITIVE AGENT AS ITS PLAYER

2.1 Multi-game

We propose a multi-game model in which players play many types of games simultaneously. This is a game theoretical model to investigate what kind of the macro dynamics of the games the interactions between the rules internalized in the players form, and what rules for forming the dynamics the agents internalize through the learning process. The minority game (MG)[4] and the *n*-person iterated prisoners' dilemma game (NIPDG)[5] are adopted here.

The MG is a simple game, where *n* (odd) players must select one out of two actions (e.g., -1 or 1, like buy or sell) independently, and those who are on the minority side win. The NIPDG is a version of the IPDG with many players. In this study, we define the NIPDG as follows: each player has to choose one of two actions, defection (D) and cooperation (C) individually; the players who chose D always win if there is one or more player who chose C; namely, when all players select D, they lose. In the multi-game, the actions D and C in the NIPDG are expressed as -1 and 1, respectively.

2.2 Dynamic cognitive agent as its game player

We adopt a model of the dynamic cognitive agent with internal dynamics represented by a simple recurrent network with a self-influential connection (SRN-SIC), as proposed in our previous work[6] and illustrated in Fig.1. The internal states of humans change even in the situations in which the same external stimulus is constantly given or when no external stimulus is given. We refer to this autonomous change of the internal states as the internal dynamics.

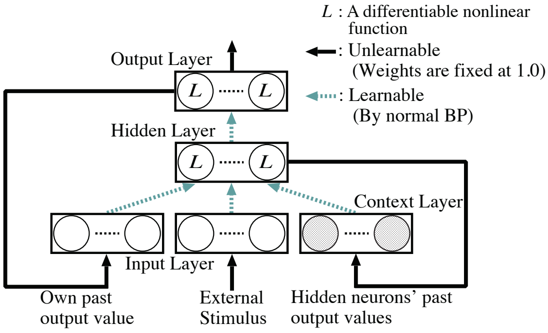

Fig. 1. The SRN-SIC proposed in our previous work as an architecture of a dynamic cognitive agent with internal dynamics.

The SRN-SIC is an Elman-type network[7] modified by adding recurrent connections between the output and input layers so that the agent can determine his/her own action based on his/her own past action, and the internal dynamics is produced by the recurrent connections.

2.3 The procedure of the multi-game

The procedure of the multi-game is as follows:

1. Except for initial time step, each agent independently decides their actions for the games based on their own past actions, internal states, and the results of the games at the last play.
2. A current game results, namely, winners' actions, are determined from all agents' actions.
3. The step is given an increment and goes to 1.

The procedure from 1 to 3 is called *one step*. By error back-propagatkon (BP) learning algorithm, all agents learn a time-series of the winners' actions in the games every 10,000 steps. A teacher's signal is the sequence of the actions at the last 100 steps immediately before the learning. We refer to the 10,000 steps as *one turn* between the learning processes.

3 SIMULATION RESULTS

Before describing the results, let's give the specification of the simulations[1]. The games are played until 10,000,000 steps; namely, 1,000 turns. The population size of the agents is 101.

[1]The settings and mathematical expressions of the SRN-SIC are omitted due to space constraints and for details to Sato and Hashimoto[6, 8].

3.1 Occurrence frequency of complex macro dynamics

First, we observe the macro dynamics expressed by a time-series of winners' actions in the games. Most of the macro dynamics have short period numbers, but sometimes complex macro dynamics represented as aperiodic motions are shaped, as illustrated in Fig.3 to be hereafter described. Fig.2 shows the average numbers of occurrences of the complex macro dynamics emerged in the games.

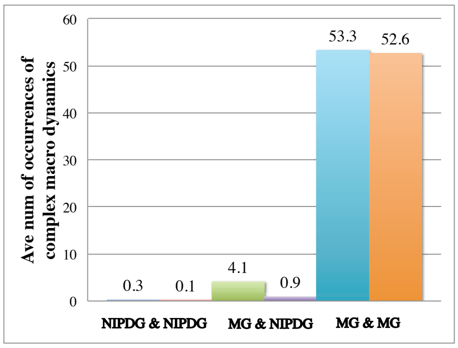

Fig. 2. Average numbers of occurrences of the complex macro dynamics in each game.

The two bar graphs on the left-hand side of Fig.2 indicate that the complex macro dynamics hardly emerge when the agents played the NIPDG and the NIPDG simultaneously. The middle two bar graphs of Fig.2 depict the results of the combination between the MG and the NIPDG. In this case, the complex macro dynamics in the MG is suppressed, although the MG is easy to shape such dynamics. The last two bars on the right-hand side of Fig.2 show the results in case that the agents played two MGs coinstantaneously. As can be seen, the number of occurrences of the complex macro dynamics is the highest of three types of game combinations. Also note that, in case of playing the MG by one group independently, the average number of occurrences of the complex macro dynamics is twenty and it was confirmed in our previous work[9]. Therefore, these results suggest that the rules shaped in the NIPDG hold enormous potential to stabilize the macro dynamics strongly, although the MG has a possibility to destabilize macro dynamics of the other game. However, the combination between the MG and the MG generates a synergistic effect to raise the frequency of occurrences of the complex macro dynamics.

3.2 Differences between the MG and the NIPDG

Second, we confirm the differences of the MG and the NIPDG from the viewpoint of the macro dynamics and the rules internalized in the agents.

Fig.3 show the examples of the complex macro dynamics[2] that emerged in the both of combined games simultaneously. Fig.3(a) illustrates the macro dynamics shaped in the MG

[2]The x-axis and the y-axis of each figure are the steps and the time-series of winners' actions converted to real numbers, respectively.

(a) Macro dynamics shaped in the MG and the NIPDG (b) Macro dynamics shaped in the MG and the MG

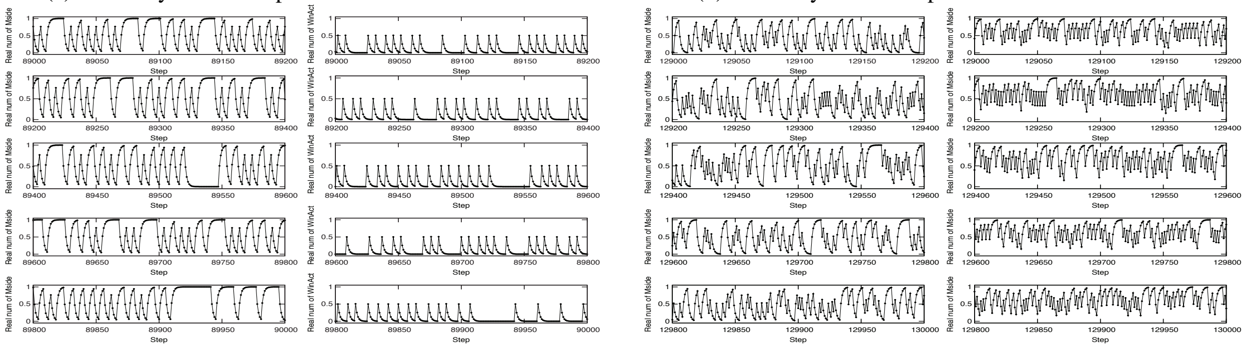

Fig. 3. Examples of complex macro dynamics.

(a) Internalized rules in the MG and the NIPDG (b) Internalized rules in the MG and the MG

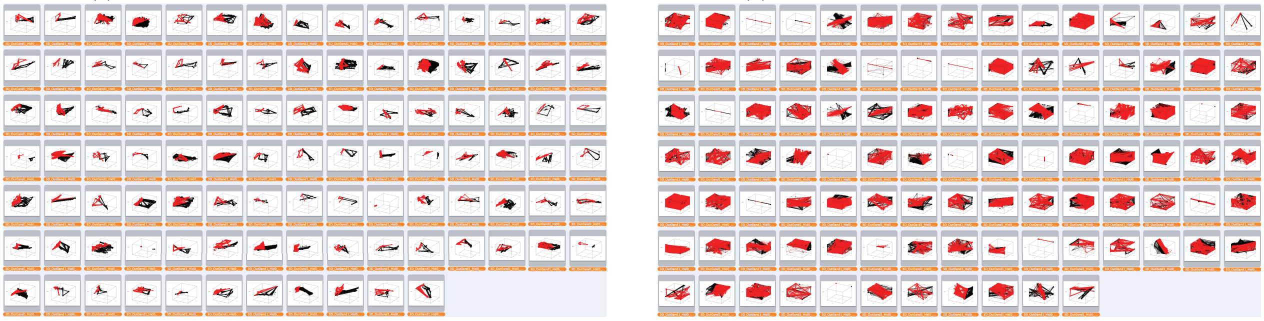

Fig. 4. Examples of rules internalized in the all agents through the learning process.

(left column) and the NIPDG (right column). Both of the dynamics are aperiodic, but change pattern of winners' actions in the NIPDG (right column) is relatively-monotonous than that of the MG (left column). In contrast, both the macro dynamics shaped by all agents who play two MGs simultaneously are very complex, as illustrated in Fig.3(b).

Fig.4 depicts the rules internalized in all agents who form the complex macro dynamics as illustrated in Fig.3. These rules are expressed as intricate geometrical shapes like strange attractors on the phase spaces which represent the relationship among two output and two hidden values[3]. The black and the red trajectories in Fig.4(a) are the internalized rules in the MG and the NIPDG, and that in Fig.4(b) are both the internalized rules in the MG, respectively.

As can be seen, each agent has two different rules to decide thier actions for the games. Furthermore, the points on the phase space of most of internalized rules illustrated in Fig.4(b) are so dense obviously. Most of these rules creates a one-to-many relationship from an input to the agent's actions, because the points on the phase space ranges over almost the entire area of the output (the x-axis on the phase space). That is to say: the rules internalized in the agents who play two MGs simultaneously, as illustrated in Fig.4(b), is more complex than that of the combination between the MG and the NIPDG, as illustrated in Fig.4(a).

[3]The x, y and z-axes of each figure are the values of the output neurons, the 1st and the 2nd hidden neurons, respectively.

3.3 Complex structures of internalized rules

In the previous section, we confirmed that the agents can internalize with different complex rules for each game through the learning process. Fig.5 gives the examples of the complex rules internalized in the agents in detail.

(a) (b)

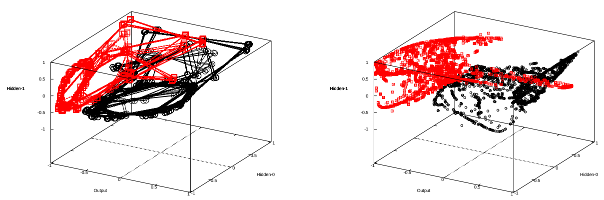

Fig. 5. Examples of complex internalized rules like combination between limit cycles and finite automaton with many states (a) and strange attractors (b).

Fig.5(a) shows the complex rules expressed by two combinations of limit cycle and finite automaton with many states. This means that the agent has the rules that can switch two action sequences with short and long periods according to the external stimuli.

Fig.5(b) can be easily imagined that the agent having this rule can output apperiodic actions. The aperiodic action may be chaotic dynamics. Chaotic dynamics has orbital instability, which expands small differences in the trajectories of agents' actions. Therefore, even a small displacement in an agents' group can induce a change in the macro level dynamics, if the number of agents with the rule that can generate the time-series of chaotic actions is much larger than that of agents without it. However, in case of playing two different games that can stabilize and destabilize the macro dynamics easily, it is considered that the agents are difficult to acquire the rules that can generate chaotic actions.

3.4 Degree of concordance of internalized rules

Finally, we analyze whether or not there is a difference between the internalized rules for the MG and the NIPDG and the ones for the two MGs. In comparison with the rules for the two MGs, it is often the case that both the rules for the MG and the NIPDG have similar or symmetric structures, as illustrated in Fig.4. This suggests that both actions decided by the rules for the MG and the NIPDG depend on the values of the same hidden neurons.

Fig.6 shows the degree of concordance of the internalized rules that are observed in the combination of the MG and the NIPDG and in the combination of the two MGs. The degree of concordance of the internalized rules is calculated as follows: correlation coefficients between each value of the output and the hidden neurons are calculated; the numbers of combinations between such neurons with strong coefficients (0.7 and more) are counted every the agents; the numbers are averaged for 1,000 turns; the averaged numbers are also averaged by the number of the agents.

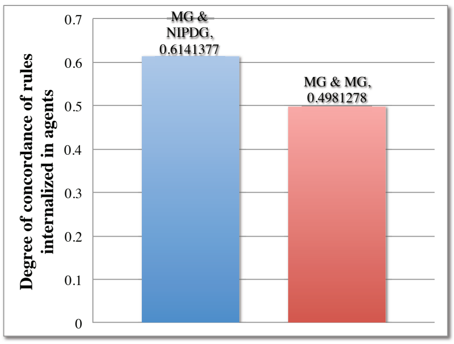

Fig. 6. Degree of concordance of rules internalized in agents

We found that there is subtle but important difference. The results in Fig.6 mean that the actions decided by both of the rules for the MG and the NIPDG are dependent on the values of the same hidden neurons than the ones determined by the rules of the two MGs. This can be interpreted that both the rules for the MG and the NIPDG have the same partial structures, and such structures can be internalized at an early stage of the games, because the agents shape only simple macro dynamics at the early stage even though they play the MG.

4 SUMMARY AND CONCLUSION

We proposed a multi-game model in order to investigate whether or not the interactions between the rules internalized in the individuals have an influence on the stabilization of the rules and the macro dynamics shaped by the rules. In this model, different games are played simultaneously by the dynamic cognitive agents who can internalize the rules through the learning process.

The simulation results showed that the agents can internalize different complex rules represented as strange attractors, but the agents are difficult to acquire the rules that can generate chaotic actions when playing simultaneously both two different games, where the macro dynamics can be stabilized easily in at least one of the games. Furthermore, we confirmed that both the rules for the MG and the NIPDG have the same partial structures, and it was suggested that such structures can be internalized at an early stage of the games, because the agents shape only simple macro dynamics at the early stage even though they play the MG.

From these results, we conclude that the followings are the important to stabilize the macro dynamics; the agents internalize different rules for each game in which at least one of the games has a feature to stabilize the macro dynamics easily, and the ones have the common partial structures between the different rules at an early stage of the games.

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