Importance of Evolved Structure for Emerging Self-organization in a Complex Competitive Situation

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Abstract

In this paper, we analyze a simple adaptive model of competition called the "Minority Game" that is used in analyzing the competition phenomena in markets. The Minority Game consists of many simple autonomous agents, and self-organization occurs as a result of simple behavioral rules. Up to now, the dynamics of this game has been studied from various angles, but so far the focus has been on the macroscopic behavior of all the agents as a whole. We are interested in the mechanisms involved in collaborative behavior among multi-agents, so we focused our attention on the behavior of individual agents. In this paper, we suggest that core elements responsible for self-organization to occur are:

1. rules of the game that potentially include a mechanism for a form of self-organization,
2. rules that place a good constraint on each agent's behavior, and
3. the existence of some rule that lead to indirect interaction; a process called "stigmergy".

Introduction

The Minority Game, which is a simulation program for analyzing models of adaptive competition that consist of many autonomous elements like those in the market (Cavagna 1998; Challet & Zhang 1997; Zhang 1998; Challet *et al.* 2001). First, we summarize the rules of the Minority Game. There are N agents, each of which independently chooses between two alternatives ("*group 0*" or "*group 1*".) In one step of the game, all of the agents choose one alternative or the other, and the agents that, as a result, belong to the minority group are awarded a point as a winner (the best case is a split of 100:101, and the worst case is a split of 1:200). The selections by each agent are based on the strategy tables that the agent holds. A strategy table consists of a set of histories that records the past m winning group choices, and a corresponding set of choices which indicates which decision to make for each history (see table 1). The strategy table contains 2^m entries, each of which consists of a {history, next decision} pair. Each agent can randomly select s strategy tables from a pool of strategy tables at the beginning of the game (all agents have the same number of strategy tables.) Each agent uses the s strategy tables in the following way. For the first step, a strategy table is randomly selected, and 1 point is given as a profit to the strategy table if one time step of the game is won or 1 point is deducted if the game is lost. In the second and subsequent time steps, the strategy table that has the highest number of points is always selected. Fig. 1 shows the standard deviation for the number of agents that chose group 0, reported in the previous studies. The game was played for the number of time steps described below for the various numbers of strategy tables possessed by the agents, $s = 2 \dots 64$ and various history depths in the strategy table, $m = 1 \dots 16$. For each parameter pair, $\{s, m\}$, the game was played for 10,000 time steps in one trial, and each trial was done in sets of 10. In this graph, the horizontal line represents the standard deviations when all the agents made their choices randomly, and the actual standard deviations were lower than for the random cases, mainly when m was 3, 4 or 5. This means that a winning group ratio that was intentionally near 100:101 arose. However, their only information is the history of past winning groups. What is characteristic is that actually a history depth of 3 cases produced good behavior, whereas a history depth of 10 rounds produces results that were the same as random behavior.

← m →			Next decision ↓
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	0
1	0	0	0
1	0	1	1
1	1	0	0
1	1	1	1

Table 1: Strategy table

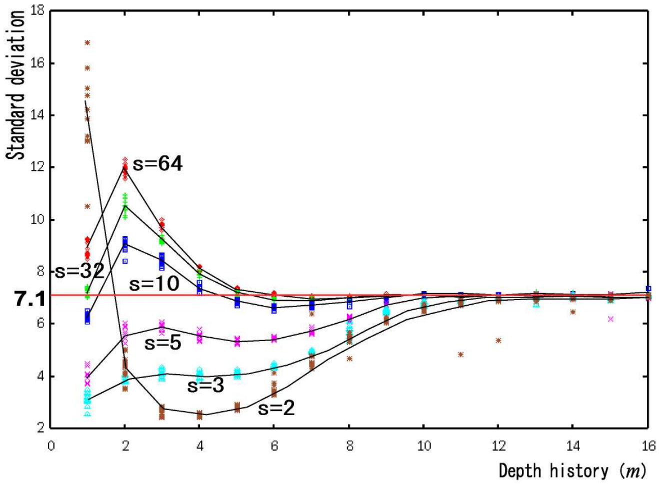

Figure 1: Standard deviation for the number of agents that selected "*group 0*"

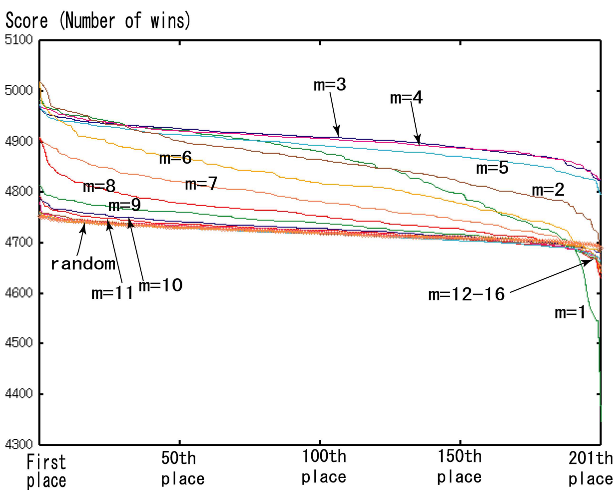

Figure 2: Agent Advantages and Disadvantages ($s = 2$)

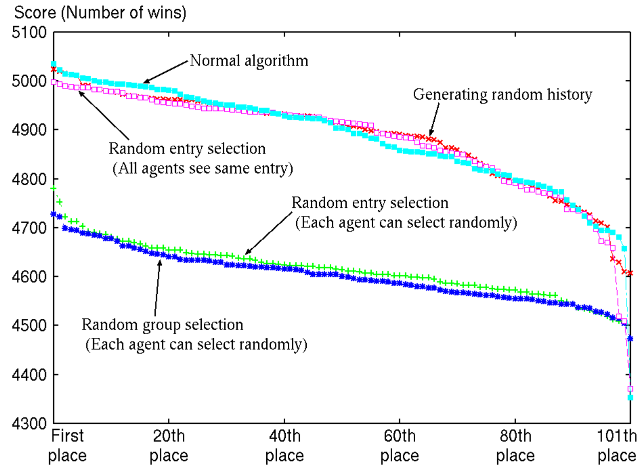

Figure 3: Is memory necessary?

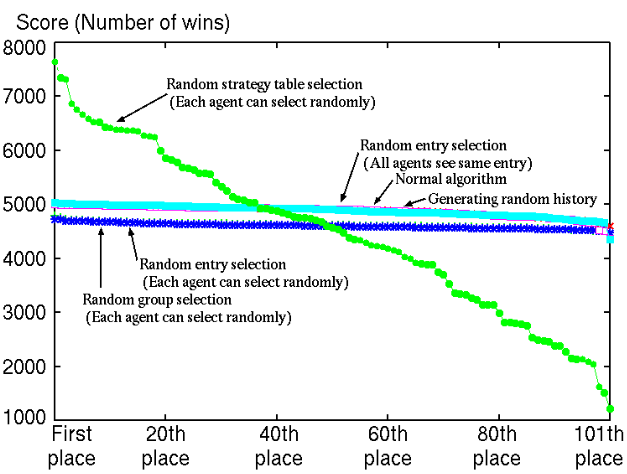

Figure 4: How to select the strategy tables

Potential advantage among agents

We investigated how many times each agent could win in several situations, and Fig. 2 shows the rankings of the 201 agents based on their average scores.

Where each agent could randomly select "*group 0*" or "*group 1*", all of the agents were only able to get approximately 4750 points. In contrast, when the standard deviation was small ($m = 3, 4, 5$), the mean score was high and, although some differences can be seen in the scores, all the agents were able to achieve stable scores. As m increased, either a large number of wins or a large number of losses occurred for a very small number of agents, but at the same time the mean score decreased, and when m was greater than 12, the trend was toward the same level as seen in the random selection case. Why, in a situation like $m = 3, 4,$ or 5, could almost all agents get higher points than for $m = 12$ or higher and the random selection case? In an attempt to explain this, we set up the following hypothesis:

[Assumption] Situations like $m = 3, 4,$ or 5 can initially produce good strategy tables, where self-organization can easily occur.

[Reason] Now, let's think about the Minority Game using five agents ($m = 3$) where each agent has two strategy tables ($s = 2$), as shown in table 2

Then, for example, if the winning group history is "010", each agent must select one of two strategy tables based on their obtained points, where the strategy of each table of entry "010" is shown as Entries-A in table 3. If the winner group history is "110", the above selected strategies will change as shown in Entries-B.

An important point is that, in this situation, even if each agent selects table 1 or table 2, four agents (Agent 1, Agent 2, Agent 3, and Agent 4) select "group 0", and only one agent (Agent 5) selects "group 1". Therefore,

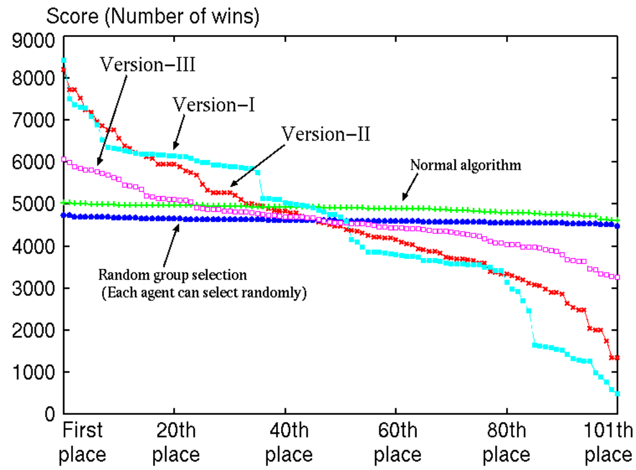

Figure 5: Existence of Stigmergy

the ratio of minority to majority becomes "group 0" : "group 1"=4:1. Also, in the situation where the winning group history is "111", two agents (Agent 1 and Agent 3) can always win (marked Entries-C).

Although the above two cases are examples of radical combinations, in a situation like $m = 3$ or 4, the possibility of including Entries-B will be low, whereas in a situation like $m = 12$ or higher, this possibility will be very high.

The reason for this is as follows. There are only five possible combinations type of Entries-B but ten of Entries-C. Further, when $m = 3$, there are only eight entries in each strategy table, but when $m = 12$, there are 4096, so, when $m = 3$, the probability of a situation like Entries-B being included is low, but when $m = 12$, a situation like Entries-B will certainly be included. Therefore, considering all the combinations of the strategy table, the combination of "group 0" : "group 1" = 2:3 or 3:2 is larger than that of "group 0" : "group 1" = 0:5 or 5:0 or "group 0":"group 1" = 1:4 or 4:1, therefore, when $m = 3$ or 4, the probability of situations like Situation-B being included is quite low and in each game, the ratio of "group 0":"group 1" is nearly always 2:3 or 3:2. Consequently, all agents can get high points.

Testing

If self-organization occurs by initial combinations of the strategy tables, the winner group history may not be an important element of the Minority Game. In other words, self-organization may be able to occur without each agent deciding its selection using the winning group history.

To test this hypothesis, we examined the following situations: In the normal algorithm, if the current winner group history is "010", each agent sees the entries of "010" of their holding strategy tables, and selects one of these depending on their points.

Agent	Hist	Strat. 1	Hist	Strat. 2
Agent 1	000	1	000	0
	001	0	001	1
	010	1	010	0
	011	1	011	1
	100	1	100	1
	101	0	101	0
	110	0	110	0
	111	1	111	1
Agent 2	000	1	000	0
	001	0	001	0
	010	1	010	1
	011	0	011	1
	100	1	100	1
	101	1	101	1
	110	0	110	0
	111	0	111	0
Agent 3	000	1	000	0
	001	1	001	0
	010	0	010	1
	011	1	011	1
	100	0	100	1
	101	1	101	0
	110	0	110	0
	111	1	111	1
Agent 4	000	1	000	1
	001	0	001	0
	010	0	010	1
	011	1	011	0
	100	1	100	0
	101	0	101	0
	110	0	110	0
	111	0	111	0
Agent 5	000	0	000	1
	001	0	001	0
	010	1	010	1
	011	0	011	1
	100	1	100	0
	101	0	101	0
	110	0	110	0
	111	0	111	0

Table 2: Strategy tables for example $m = 5, s = 2$ game

At this stage, we raise the following questions:

1. If each agent is allowed to select the entry of strategy tables randomly, can self-organization occur?

2. If only one agent-A is allowed to select the entry using its own rules based on the winning group history and the other agents use the same entry as agent-A, can self-organization occur? The game's rules are where agents can decide which entry to use on their own, not by the winning group history.

3. If we intentionally generate a random winner group history, can self-organization occur?

If self-organization can be formed in the above situations, our hypothesis that the memory of the winner group history is ineffective may be correct.

Fig. 3 has the memory results: the same self-organization as in the normal algorithm could occur in

Entries-A			Entries-B			Entries-C		
Agt	S1	S2	Agt	S1	S2	Agt	S1	S2
1	1	0	1	0	0	1	1	1
2	1	1	2	0	0	2	0	0
3	0	1	3	0	0	3	1	1
4	0	1	4	0	0	4	0	0
5	1	1	5	1	1	5	0	0

Table 3: Strategy outcomes for various winning histories: Entries-A="010", Entries-B="110" and Entries-C="111".

situations (2) and (3). Even when we established a random winner group history, and none of the agents used the entry of the strategy tables that depended on the memory of history, they could organize themselves well. This means that the memory of the winner group history may not be important in self-organization. However, when each agent could select the entry of strategy tables randomly, their behaviors were the same as for the random selection version. Therefore, an important point concerning the strategy tables is that, in the normal algorithm, the winner group history applies a constraint that has evolved from the agents' using the strategy tables. In other words, we can use any kind of rule that enables us to apply a constraint on using strategy tables like situation (2). Applying a good constraint on the agents means the same as decreasing their freedom, and through this constraint, organization must occur. In a previous work (Kurihara, Onai, & Sugawara 1998), we also discussed how to achieve self-organization by using other frameworks, and came to the same conclusion we have in this study.

Indirect interaction

If self-organization is formed only by the mechanism based on our hypothesis, then it raises the following question: Even if each agent can select the strategy tables randomly, will the game results be the same as with the normal algorithm? Fig. 4 has the results for how the strategy tables are selected. If each agent could select the strategy tables randomly, there would be a very big gap between the winner and loser and self-organization would not occur. This means that, in the Minority Game, indirect interaction between agents is also an important element of organization forming. The reason is as follows. The process whereby each agent selects strategy tables by points means that they decide their behavior based on the results of each step, and their decision changes in the next step.

At this point, if we change the rules for selecting the strategy tables, will self-organization still occur? Fig. 5 plots the results of doing this. We implemented the following rules.

(Version-I) Each agent selects one of two strategy tables in turn. The interval of the exchange is randomly set up.

(Version-II) If it wins, 1 point is add to the selected strategy table, but if it loses, 2 points are subtracted.

(Version-III) If the agent loses one game, the strategy table is changed even if the table produced several wins.

Unfortunately, self-organization did not occur using any of these versions. The way the strategy table is selected must bear a close relationship with the initial combinations of the strategy tables of each agent, so a detail investigation will be necessary to determine what is an essential mechanism responsible for selecting strategy tables, and this is for future work.

Can we easily control agents?

In terms of the strategy tables, if we assume that the variance in the correlations within agents and the correlations between agents has a major effect on good scores, then we can expect that a change in the behavior of the agents will result from intentionally increasing the variance. Therefore, we selected one appropriate agent from among the 201 agents, and 19 agents were made to positively (100%) correlate with that agent. This means that they possessed exactly the same set of strategy tables. In addition, 20 agents were made to have reverse (−100%) correlation with that agent. This means that their behavior was always the opposite, and the game was played with $m = 3$, for which good scores were obtained, and with $m = 12$, for which the results were the same as for random choices. The results for these two cases are compared in Figs. 6 and 7.

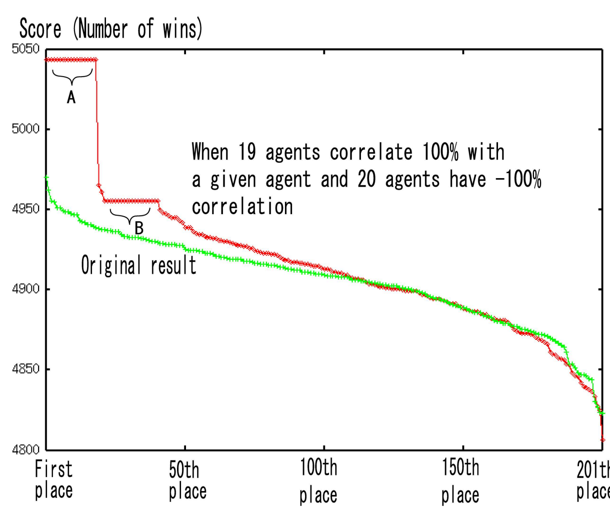

Figure 6: For $m = 3$

This comparison yields profoundly interesting results. Initially, we expected that one of the two groups of 20

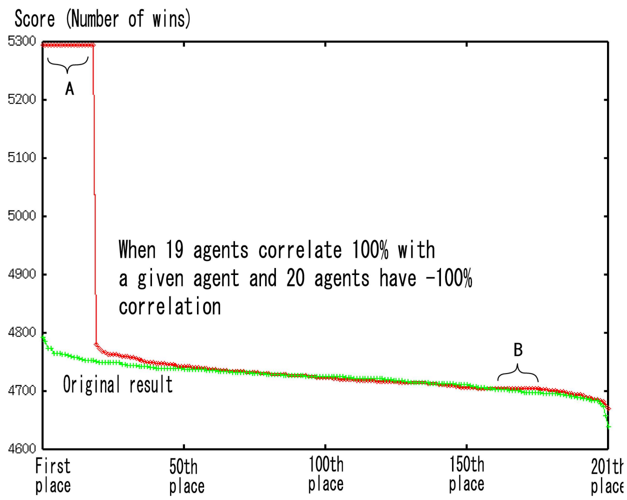

Figure 7: For $m = 12$

agents (either the 100% group or the −100% correlation group) would get the highest scores and the other group would get the lowest scores. Contrary to our expectations, both groups were able to attain high scores. Moreover, the overall average scores for the agents as a whole improved considerably, for both cases ($m = 3$ and $m = 12$), as a result of intentionally setting the behavior of the 40 agents, and the scores of the other agents that were not modified also improved above the agent ranked in 100^{th} place. In addition, the scores of the agents in the vicinity of the lowest score also increased.

These results strongly suggest that agents that possess strategy tables that have extremes of positive and reverse correlations are a major factor in improving the efficiency of the collective behavior of the agents as a whole, and we are currently in the midst of evaluating various changes in the settings.

Conclusion

In this paper, we analyzed a simple adaptive competition model called "the Minority Game," which is used in the analysis of competition phenomena in markets. The Minority Game consists of many simple autonomous agents, and self-organization occurs through simple behavioral rules.

As we were interested in the mechanisms for collaborative behavior in multi-agent systems, we focused our attention on the behavior of individual agents. We suggest that core elements for self-organization to occur are:

1. rules of this game that potentially include a mechanism for a form of self-organization,
2. rules that place a good constraint on each agent's behavior, and
3. the existence of some rule that lead to indirect interaction; a process called "stigmergy".

In terms of the rules for good constraint (2), A. Cavagna (1998) suggested basically the same as us. He said that, in the Minority Game, the memory of the winning group is irrelevant, and the important point is sharing data among agents. However, we think that it is more important to place a good constraint on agents' behaviors, and to constrain them to share some data. In the normal algorithm, this data is designed for use by the winning group history. Finally, in terms of stigmergy (3), a detailed investigation will be necessary to clarify the essential mechanism responsible for selecting strategy tables. Of course, we will continue with further analysis aimed at establishing a general algorithm that can be applied to other competition problems.

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