Simple but Efficient Collaboration 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, which is used in analyzing competitive phenomena in markets, and suggest that the core elements required for the formation of self-organization are: (i) rules that place a good constraint on each agent’s behavior, and (ii) rules that lead to indirect coordination, which is called “stigmergy.” Finally, we tested the points suggested by this research in solving the El Farol’s bar problem, which is an extended version of the Minority Game.

Categories and Subject Descriptors
I.2.11 [Artificial Intelligence]: Distributed Artificial Intelligence

General Terms
Theory, Experimentation

Keywords
Minority Game, multi-agent, self-organization, stigmergy.

1. The Minority Game
The Minority Game [1] has been thoroughly studied in econophysics and looked at from various other angles, but, in nearly all of those studies, the researchers were concentrating on the behavior of the game as a whole. We have thus investigated the behavior of the individual agents of the game to discover the patterns that lead to efficient overall behavior.

We have N agents, each of which is an autonomous actor that independently chooses between two alternatives (group 0 or group 1) according to its own intent. In each round of the game, all of the agents choose one or the other alternative, and the agents that then finish in the minority group are considered to be winners and are each awarded one point. The smaller the difference in number between the majority and minority groups, the better the result. The selections are based on strategy tables that the agent holds. A strategy table consists of a set of histories, each of which contains all combinations of m past winning-group choices and a next decision that corresponds to each combination (see Fig. 1). At beginning of the game, each agent randomly selects s strategy tables. In the first time step (round), a strategy table is selected randomly; the agent is given an artificial history and uses this to make a choice. If the agent wins, one point is assigned as profit to the strategy table; one point is deducted for a loss. In the second and subsequent time steps, the strategy table that has the highest number of points is always selected. This rule is repeatedly applied for a predetermined number of rounds, and the results of the game are the total numbers, across all rounds, of agents that selected each of the minority group. Fig. 2 shows the standard deviation of the number of agents that chose group 0; the horizontal line represents the standard deviation when all of the agents made their choices randomly.

2. Keys to the formation of self-organization
In the Minority Game, the following two rules are important: (i) each agent consults its strategy tables according to winning-group history, and (ii) each strategy table's score is affected by both wins and losses.

2.1 A winning-group history is unnecessary
When we assign small value to m, the standard deviations were generally lower than for the random case, particularly when m was 3, 4, or 5. This shows some process had arisen to drive the winning-group ratio near to 100:101, which is to say that the agents were showing some form of collaborative behavior, even though the individual agents are incapable of knowing about each other’s behavior.

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AAMAS’03, July 14–18, 2003, Melbourne, Australia.
ACM 1-58113-683-8/03/0007.
Does self-organization still occur if each agent randomly selects entries from the strategy tables? (ii) Does self-organization still occur if we generate and assign random winning-group histories? We thus formulated simulations to find the answers. Fig. 3 shows the result: the same self-organization as with the normal algorithm is formed in the simulation set up for (ii). Even when we made random winning-group histories, and none of the agents were using memory to select entries from the strategy tables, they still became well organized. This result shows that the memory, i.e. the winning-group history, may be superfluous to the self-organization. However, when each agent randomly selected entries from the strategy tables, their overall behavior was the same as in the random-selection case. Therefore, an important point with regard to the strategy tables is that, in the normal algorithm, dependence on the winning-group history simply places a good constraint on the use of the strategy tables. In other words, we may be able to use any kind of rule that places a good constraint on the use of the strategy tables, as in simulation (ii).

2.2 The importance of indirect coordination

In the Minority Game, indirect interaction between agents is a further important element in the formation of organization. At this point, we ask whether or not self-organization will still be formed if we change the rule used to select strategy tables. Fig. 4 shows the result of our investigation of this question. We implemented the following rules. (Rule I) Agents select each of the strategy tables in sequence. The interval of table exchange is randomly selected before each simulation run. (Rule II) The normal Minority Game rules apply, except that one point is added to the selected strategy table if the agent wins and two points are subtracted if it loses. (Rule III) If the agent loses one game, the strategy table is changed, even if the table previously produced several wins.

Unfortunately, roughly equal proportions of agents won and lost in all of these cases, i.e. we saw no self-organization. One bad phenomenon was the presence of several agents which either won or lost in almost every rounds.

3. Can we resolve the El Farol’s bar problem?

The El Farol’s bar problem [3] is similar to the Minority Game; the only difference is the following rule in the former case: a desired ratio between the numbers of agents in the minority and majority groups is pre-defined (e.g. 1:3 or 1:5). We try applying our findings to this problem by making strategy tables in the following way: In the Minority Game, the strategy table is such that items ‘0’ and ‘1’ are chosen with equal probability, but in the El Farol’s bar problem, the probabilities match the target ratio. If the pre-defined ratio is set to 1:3, we generate the strategy tables by selecting item ‘0’ once in every three selections of item ‘1’. Such usage of the strategy tables means that the number of agents that select group 0 is almost always fewer than the number selecting group 1, so we only assign and deduct one point when the strategy table’s next decision was group 0. The remaining rules are the same as the rules of the Minority Game. Table 1 shows the standard deviation in the numbers of agents that won the game by using our algorithm and by random selection. In every situation, the standard deviation of our algorithm was lower than that for random selection. Fig. 5 shows the ranking of the 101 agents when the average scores of the pre-defined ratio were set as (group 0):(group 1)=1:1, 1:2, 1:3, 1:7. As you can see, most agents received a higher score with the algorithm.

<table>
<thead>
<tr>
<th>Gr.0:Gr.1</th>
<th>Our algorithm</th>
<th>Rand.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:1</td>
<td>0.95</td>
<td>5.02</td>
</tr>
<tr>
<td>1:2</td>
<td>1.75</td>
<td>4.89</td>
</tr>
<tr>
<td>1:3</td>
<td>0.61</td>
<td>4.40</td>
</tr>
<tr>
<td>1:7</td>
<td>1.06</td>
<td>3.38</td>
</tr>
</tbody>
</table>

Table 1: Standard deviation of the number of agents that selected “group 0”

4. Conclusion

In this paper, we have analyzed a simple model of adaptive competition which is called the Minority Game and suggested that the core elements for forming self-organization are: (i) the application of a good constraint to each agent’s behavior and (ii) indirect coordination, which is called “stigmergy.” With regard to point (i), A. Cavagna [2] says that the memory of the winner group is irrelevant and the important point is the sharing of some data among the agents. However, we want to suggest that the important point is to place a good constraint on the behavior of the agents. As for (ii), a detailed investigation will be necessary to clarify the essential mechanism in the selection of strategy tables. Finally, we tried to solve the El Farol’s bar problem and found that the agents show collective order when they simply operate by rules that embody core elements (i) and (ii).

Reference