An Investigation into the Use of Group Dynamics for Solving Social Dilemmas

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Abstract. In this research, we propose some group dynamics that promote cooperative behavior in systems with social dilemmas and hence enhances their performance. If cooperative behavior among self-interest individuals is established, effective distribution of resources and useful allocation of tasks based on coalition formation can be realized. In order to realize these group dynamics, we extend the partner choice mechanisms for 2-IPD to that for N-person Dilemma game. Furthermore, we propose group split based on metanorm as a new group dynamic. A series of evolutionary simulations confirm that this group dynamic: i) establishes and maintains cooperation, and ii) enhances the performance of the systems consisting of self-interest players in Social Dilemmas situations.

1 Introduction

Recently, multiagent systems have applied more and more frequently as a framework for constructing large distributed systems. The introduction of autonomous collaborating agents gives more flexibility and efficiency to systems. In multiagent systems, usually the agents have only incomplete information and limited ability to solve problems in the environment [9, 19]. Faced with a problem it cannnot solve, an agent may seek to get together with other agents and form a collaborative group. The question is then whether cooperative behaviours will result from such a group. It is difficult to promote cooperative behaviors in the case that an individual agent can acquire a higher reward by non-cooperative behavior even though cooperative behaviour by all would maximise the reward of all [5, 6, 8, 10, 15, 16]. This situation is generally called a Social Dilemma [11], where free-riders who choose non-cooperative behaviors decrease the total reword in the group. In multiagent systems, this problematic situation is often observed in resource distribution and task allocation without central authority. Self-interest agents do not choose a e cooperative behavior for maximizing the reward of the group because they prefer the individually best outcome to the collectively best outcome. If some decentralised mechanisms ca be devised to prevent free-riders from joining cooperative groups, the total reward in the group can be increased and the performance of the systems can be enhanced. Therefore group dynamics which do not require the existence of

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central authority, are one of the most important mechanisms promoting cooperation in multiagent systems.

In this paper, in order to realize effective group dynamics in dilemma situation, we use the mutual choice mechanisms [1, 18, 20] as the basic interaction for group formation, which is the matching mechanism in a multiple 2-person Prisoner's Dilemma (2-PD). Some previous researchs revealed that the conventional partner choice mechanisms for matching two persons can promote the establishment of coopeartion [7, 12, 14, 17]. Here a more general dilemma situation is investigateed, the iterated N-person Prisoner Dilemma game. Furthermore, we propose a group split rule based on the concept of metanorm [2]. The effect of our proposed group dynamics on the enhancement of system performance is confirmed through an agent-based simulation with evolutionary approach.

2 Group Dynamics

In this paper, we use mutual choice for the matching mechanism in multiple 2-P PD games, to show how effective group dynamics can be in dillema situations.[1] Group dynamics in the dilemma situation are modeled as a 2 stage game. The first stage is where agents choose group members. The groups are determined through some group dynamic mechanism, – a population of all agents is partitioned. A group is defined as a subset of the overall agent set. Each agent can join only one group at any one time. The order of decision-making by the agents is set as random. According to this order, the agents make decisions one by one, so that groups are gradually formed. The second stage is a dilemma game. In the groups consisting of two or more agents, agents play the N-PD with their group members. The result of the N-PD in a group is independent of the agents in other groups. Where groups consist of a single agent, that agent acquires a fixed payoff.

2.1 Unilateral Choice

In group formation based on unilateral choice [13], agent i can join group k surely, i.e., group k cannot refuse agent i. Each agent has the alternative of forming a new group or joining an existing group. Agent, i, chooses a group, k, which is the most tolerable to it. Agent i is then added to group k. If there is no tolerable group for agent i, agent i makes no offers and forms a new group.

2.2 Mutual Choice

In group formation based on mutual choice, the agent making an offer and the group receiving it form a new group only if both agree. Therefore, a group has the possbilities of either refusing or accepting an offer. After agent i makes an offer to group k (this process is the same as that for unilateral choice.), group k can decide to refuse or accept agent i by majority vote based on the decision of all members. If the majority of agents in group k agree to accept player i, group k accepts the offer of agent i and then agent

[1] For more details see Yamashita and Ohuchi[21].

i joins group k. If group k refuses agent i, agent i makes an offer to the second most tolerable group. Agent i continues making offers until a group accepts its offer or until all groups tolerable to it refuse its offer. If agent i is refused by all tolerable groups, agent i forms a new group.

2.3 Group Split

A group split rule is proposed based on the concept of a metanorm. According to Axelrod [2], if there is a certain norm, a metanorm is to "punish, not only against the violators of the norm, but also against anyone who refuses to punish the defectors." In this model, a norm based on mutual choice is "don't choose defectors as group members." A metanorm based on mutual choice is "don't choose, not only defectors, but also anyone who choose defectors as group members." This metanorm effectively realizes group split by dividing the group of agents agreeing to the acceptance of an agent (agreeing agents) and the other group opposing this (opposing agents). From the point of view of the opposing agents, the agreeing agents violate the metanorm because the agreeing agents choose the agent that opposing agents consider to be a defector. In order not to choose the agents who choose defectors as group members, the opposing agents leave from the group.

2.4 Re-offering

By the introduction of the rule of group split, the number of groups of only one agent may increase. Re-offering is proposed as a mechanism to increase the chance of creating a group of several agents as soon as possible.

2.5 Dilemma Game

In this model, we use a more general dilemma game than the N-PD in [6]. After the group dynamics, the players in each group play the dilemma game with group members if the players are in groups of more than two players. Otherwise, a player in a group only consisting of itself acquires the fixed payoff for lone players, the $reservation\ payoff$ $P_{reservation}$, instead of the payoff of the dilemma game [1, 18, 20]. Each group member decides its contribution to its group, and then the profit given by the total contibuted by all members is redistributed equally to the group members. Each player i in group k contributes some amount, $x_i \in \{0, 1\}$, to group k as the strategy, and has a payoff function, F_i. The total contribution of all players in group k amounts to $X \equiv \sum_{i \in G_k} x_i$. The payoff function of player i in group k can be written as

$$F_i(x_i; X, |G_k|) = a\frac{X}{|G_k|} + b(1 - x_i) \tag{1}$$

where $|G_k|$ is the size of group k, and a and b are positive constants.

3 Simulation

In our simulations, a genetic algorithm (GA) is applied to evolve the player's strategies [3, 4]. The two dimensions of a strategy, cooperativeness C_i and vengefulness V_i, are each divided into $2^x - 1$ equal levels, from 0.0 to 1.0. Because $2^x - 1$ levels are represented by x binary bits, a player's strategy needs a total of $2x$ bits: x bits for cooperativeness C_i and x bits for vengefulness V_i.

Each generation consists of an iteration of group formation and split processes, and then the Dilemma game. At the beginning of the GA, each player's strategy in a population is assigned a fitness equal to its average payoff given per payoff received. Uniform crossover is applied to the strategies of a player and a partner to obtain a new strategy for one offspring if the fitness of the partner is better than that of the player in tournament selection.

Since our purpose is to examine whether the group dynamics we investigate can promote cooperative behavior amoung players and enhance the performance of systems, we pay attention to the development of players' strategies and the average payoff of all players. In order to confirm the effect of the proposed group dynamics, we compare four settings: case 1) only group formation based on unilateral choice, case 2) only group formation based on mutual choice, case 3) group formation based on mutual choice and group split, and case 4) group formation based on mutual choice, group split and re-offering. We define the establishment of cooperation as the situation where both the average cooperativeness of all players ($\overline{C}$) and the average vengefulness ($\overline{V}$) are bigger than 0.8. The important parameters are shown in Table. 1.

3.1 Establishment of Cooperation

The number of times cooperation is established in 40 trials of the four cases is 0 in case 1, 4 in case 2, 12 in case 3, and 40 in case 4. In all trials of case 1, there was little cooperativeness and vengefulness, i.e., cooperation was not established at all within 5,000 generations. In 36 trials of case 2, cooperation was not established within 5,000 generations. In the remaining 4 trials, there were great deal of cooperativeness and vengefulness, i.e., cooperation was established. In 28 trials of case 3, cooperation was not established within 5,000 generations. In the remaining 12 trials, cooperation was established. In all trials of case 4, cooperation was established.

Three typical developments of the average cooperativeness and vengefulness of players are shown in Figs. 1, 2, and 3. In these graphs, the horizontal axis represents the gen-

Table 1. Common parameters in the simulations

Number of players	50
Number of generations	5000
Number of group dynamics per generation	200
Coefficient of payoff function a	1.0
Coefficient of payoff function b	0.6
Payoff for lone player $P_{reservation}$	0.1
Initial value of expected cooperation π	1.0
Initial value of Cooperativeness C_i	0.0
Initial value of Vengefulness V_i	0.0
Mutation rate	0.05
Binary bits for C_i and V_i (total bits)	10

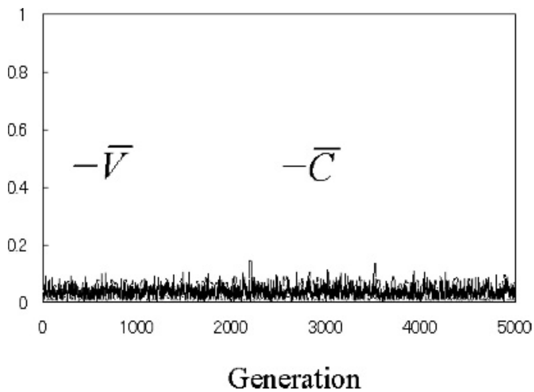

Fig. 1. Example of the failure of the establishment of cooperation in case 1: the average cooperativeness $\bar{C}$ and vengefulness $\bar{V}$ from 0 to 5,000 generations

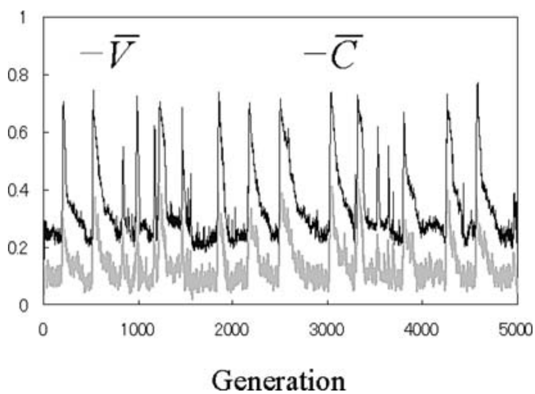

Fig. 2. Example of the failure of the establishment of cooperation in case 2 and 3: the average cooperativeness $\bar{C}$ and vengefulness $\bar{V}$ from 0 to 5,000 generations

eration, and the vertical axis represents the average cooperativeness and vengefulness of players. The typical behavior of $\bar{C}$ and $\bar{V}$ in case 1 for 5,000 generations is shown in Fig. 1. Throughout the generations, $\bar{C}$ and $\bar{V}$ fluctuated in the range of 0.0 to 0.1. The typical behavior of $\bar{C}$ and $\bar{V}$ in case 2 and 3 when cooperation was not established is shown in Fig. 2. Usually, $\bar{C}$ remained in the range of 0.0 to 0.2 and $\bar{V}$ remained in the range of 0.2 to 0.4. However, occasionally $\bar{C}$ rose to 0.4 and $\bar{V}$ fell to 0.3, and then $\bar{C}$ and $\bar{V}$ returned to their initial states. This fluctuation was repeated throughout the generations. The typical behavior of $\bar{C}$ and $\bar{V}$ in case 2, 3, 4 when cooperation was established is shown in Fig. 3. Once $\bar{C}$ and $\bar{V}$ reached 1.0, this state continued to remain there and did not transfer to another state.

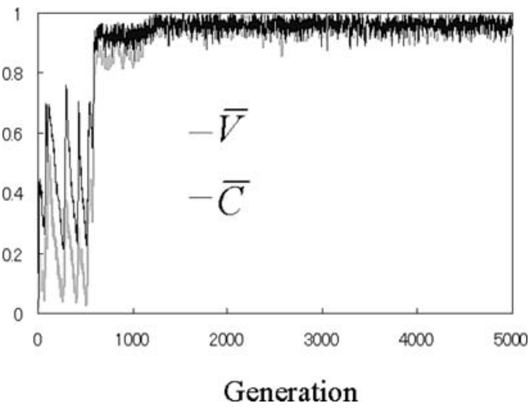

Fig. 3. Example of the establishment of cooperation in case 2, 3, 4: the average cooperativeness $\bar{C}$ and vengefulness $\bar{V}$ from 0 to 5,000 generations

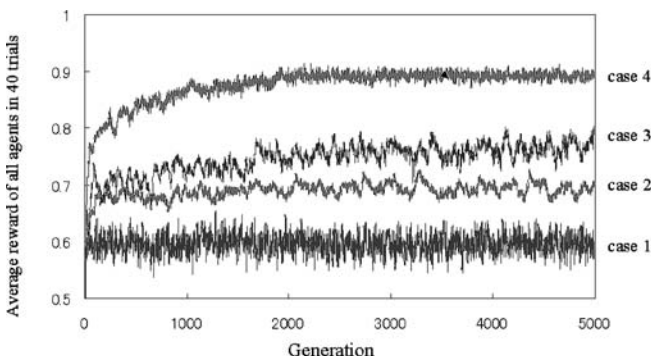

Fig. 4. The average payoff of all players in 40 trials of four cases of group dynamics

3.2 Average Payoff

The average payoffs of all players in 40 trials of four cases are ranked in descending order as case 4, 3, 2, 1. In the graph of Fig. 4, throughout all generations, the average payoff of unilateral choice continued to fluctuate near 0.6. The average payoff of mutual choice also continued to be near 0.7. The average payoffs of mutual choice with the split rule continued to slightly rise from 0.7 to 0.8. The average payoffs of mutual choice with the split rule and re-offering rose to 0.9 until 2,000 generations. After 2,000 generations, it seldom changed.

4 Discussion

We discuss the establishment of cooperation based on the strategy (C_i and V_i) in four cases and the enhancement of systems' performance based on the average payoff of all players. In the following discussion, a player with a high level of cooperativeness is represented as C_{high}, and a player with a low level of cooperativeness as C_{low}. In the same way, a player with high and low levels of vengefulness are represented as V_{high} and V_{low}, respectively.

4.1 Establishment of Cooperation

Case 1. In all trials in case 1, why did the establishment of cooperation fail? A player with low cooperativeness as the result of a mutation (i.e., a player with C_{high}), cannot acquire a higher payoff than the players with C_{low}. The reason is that the players with C_{high} cannot refuse an offer from the players with C_{low} in a group dynamic based on unilateral choice, so the players with C_{low} have a free-ride on the players with C_{high}. Accordingly, the players with C_{high} do not increase in the next generation. Therefore, cooperation is never established.

Case 2. In 36 trials of case 2, why did the establishment of cooperation fail? We analyze the factors leading to the failure of cooperation based mutual choice.

First, we consider the case where there is only one player with C_{high} and V_{high}. Mutation decreases cooperativeness or increases vengefulness because the initial condition is $V_i = 0$ and $C_i = 0$ $(\forall i \in N)$. A player with cooperativeness decreased by mutation, i.e., a player with C_{high}, cannot acquire a higher payoff than the players with C_{low} because the players with C_{low} can freeride on the players with C_{high}. Accordingly, the players with C_{high} do not increase in the next generation. A player with vengefulness increased by mutation, i.e., a player with V_{high}, cannot acquire a higher payoff than the players with C_{low} because players with V_{high} do not join a group consisting of players with C_{low}. Therefore, one player with C_{high} and V_{high} by mutation cannot acquire a higher payoff than the players with C_{low} and V_{low}. Consequently, the player with C_{high} and V_{high} is not selected in the genetic operation, and so it perishes.

Next, we consider the case where there are several players with C_{high} and V_{high}. If a group consists of only players with C_{high} and V_{high}, the group refuses the offers of players with C_{low}. If a group consists of both players with C_{high} and V_{high} and players with C_{high} and V_{low}, it is possible that a player with C_{low} would join this group and be able to free-ride. The player with C_{low} can join the group because, while the players with C_{high} and V_{high} oppose the acceptance of his/her game offer, the players with C_{high} and V_{low} agree to it. If the players with C_{high} and V_{low} win the majority vote over the players with C_{high} and V_{high}, the player with C_{low} can join the group. In such a group, the players with C_{low} free-ride on the players with C_{high}. The players with C_{high} and V_{high} are not selected in the genetic operation and then perish because they cannot acquire higher payoffs than the free-rider. Although there are plural players with C_{high} and V_{high}, the players with C_{low} and the players with C_{high} and V_{low} prevent the establishment of cooperation. The players with C_{low} directly prevent the establishment of cooperation because they free-ride on the players with C_{high} and V_{high}. On the other hand, the players with C_{high} and V_{low} indirectly prevent the establishment of cooperation because they accept offers from the players with C_{low} who free-ride on the players with C_{high}. In the group dynamics based on mutual choice, therefore, the establishment of cooperation often fails.

On the other hand, in the remaining 4 trials, why did the establishment of cooperation succeed? Here, we analyze the factors leading to the establishment of cooperation in these cases. The reason for the establishment of cooperation was that a player with C_{low} can join the group consisting of both players with C_{high} and V_{high} and players with C_{high} and V_{low}. If there are players with C_{high} and V_{high} but no player with C_{high} and V_{low}, the player with C_{low} cannot join the group, and then the players will defect from each other. As a result, the player with C_{low} acquires a lower payoff than the players with C_{high} and V_{high} who cooperate with each other. If the number of players with C_{high} and V_{high} increases, and the players predominate in the population for a few generations before the number of players with C_{high} and V_{low} increases by crossover or mutation, cooperation becomes established. Therefore, since the simulation results show that cooperation was established in 4 out of 40 trials, we can conclude that it is not impossible but difficult to realize the establishment of cooperation in the group dynamics based on mutual choice.

Case 3. In 12 trials of group dynamics in case 3, why did the establishment of cooperation succeed? In case 3, the establishment of cooperation fails because the players with C_{high} and V_{low} accept the offer of the players with C_{low}. Here, we analyze the factors leading to the establishment of cooperation in the group dynamics based on mutual choice with the split rule.

In these group dynamics, if the players with C_{high} and V_{low} agree to accept the offer of a player with C_{low}, and the group as a whole also accepts it, the players with C_{high} and V_{high} leave the group based on the split rule; they refuse to play the dilemma game with those who play with defectors. The split rule prevents the player with C_{low} from having a free-ride on the players with C_{high} and V_{high}. This is because if the player with C_{low} joins the group, the players with C_{high} and V_{high} leave. As a result, if there are some players with C_{high} and V_{high}, they can form a group without the player with C_{low}. The players with C_{high} and V_{high} can acquire higher payoffs because they cooperate with each other. Throughout this process, the number of players with C_{high} and V_{high} increases and they predominate in the population. Therefore, cooperation becomes established.

Case 4. In all trials of group dynamics in case 4, why did the establishment of cooperation succeed? Based on group dynamics based on mutual choice and group split, a player with C_{high} and V_{high} sometimes leaves its group and then joins a group consisting of only itself. In this case, the player with C_{high} and V_{high} acquires the payoff of the loner, which is lower than those in a group. If the player with C_{high} and V_{high} has a chance of re-offering, the player leaving from one group may be able to join another group. The player with C_{high} and V_{high} can avoid acquiring a lower payoff by mutual cooperation if another group consisting of many players with C_{high} exists. The re-offering of a player leaving a group increases the chance for players with C_{high} and V_{high} to acquire a higher payoff. Accordingly, the establishment of cooperation increases because the players with C_{high} and V_{high} do not decrease in the next generation.

4.2 Comparison of Average Payoffs

In this research, we compare the effect of the proposed group dynamics using the average payoff because the average payoff can be considered as a measure of the system performance. Based on the comparison of the average payoffs, the effect of four cases is ranked in descending order as case 4, 3, 2, 1. >From the development of the average payoffs, we can acquire the following results concerning these group dynamics. In relatively early generations, the effect of the split rule doesn't provide good results for the establishment of cooperation because there is not a great difference between case 3 and 4.

5 Conclusions

In this paper, certain gourp dynamics were proposed in order to enhance the performance of systems of self-interested agents. The partner choice mechanisms for the multiple 2-PD were extended to that for a multiple N-person dilemma game to study this. Four kinds of group dynamics based on partner choice mechanisms were investigated: case 1) only group formation based on unilateral choice, case 2) only group formation based on mutual choice, case 3) group formation based on mutual choice and group split, and case 4) group formation based on mutual choice, group split and re-offering. In order to measure the effect of these on the establishment of cooperation and the enhancement of system performance, an agent-based simulation was used. Evolutionary agent-based simulations were conducted to confirm whether these group dynamics with the split rule could promote cooperative behavior of players and enhance the performance of systems.

On the establishment of cooperation, the following results were confirmed: in group dynamics with group formation based on only unilateral choice, it is impossible to establish cooperation. In group dynamics with group formation based on monly utual choice, it is not impossible but difficult to establish cooperation. Similarly, in group dynamics with group formation based on mutual choice and group dynamics, it is difficult to establish cooperation. In group dynamics with group formation based on mutual choice and group formation and re-offering, it is possible to reliably establish cooperation. Finally, it was confirmed that these group dynamics has a large enough effect to increase the performance of systems if these included group split and re-offering.

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