Proceedings of ITC-CSCC 2000, Pusan, Korea

Evolution of Cooperative Behavior in Distributed Social Dilemma

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Abstract
In previous research of social dilemma, there is no extended game that the players can select one game out of some social dilemma games. We propose this kind of game as "Distributed Social Dilemma". In this game, each player tries to acquire the adaptive strategy throughout local interactions. We make use of GA as evolutionary operations. In this paper, our purpose is to examine how the game selection of players influences the evolution of cooperation in distributed social dilemma. In order to examine, we formulate distributed social dilemma by Game Theory and use agent-based simulation that each agent is regard as player

1 Introdution

The causes of social dilemmas are the limited public goods and the individual selfish behaviors. Examples of social dilemmas are easy to find: protecting the environment, conserving natural resources and containing the world population. In previous studies on social dilemmas [1, 2, 7, 8], there is no extended game that players can select one game out of some social dilemma games [4]. Individual players have no control over which opponents they play. In real world, however, players do not always have no alternative but to play their assigned social dilemma game. Social interactions are often characterized by the preferential choice of game itself. In our research, in order to represent such a situation, we propose "Distributed Social Dilemma", in which players select one game out of some social dilemma games and then decide to cooperate or defect there.

Social dilemmas exist in not only real world but also artificial society. In artificial society, selfish behaviors of autonomous agents may cause social dilemmas because each agent behaves based on its own free will and personal motive and network resources as public goods are limited. Furthermore, distribution of computer network systems is making rapidly in recent years. When autonomous agents are constantly on the move to achieve their aims in distributed computer network systems, agents can consider one object of distributed system as artificial society. In other words, agents can consider distributed system as a set of multiple artificial society. Therefore, if there is social dilemma situation in each artificial society (each object), each agent has a right to select one artificial society as place of activity out of some artificial societies.

In this paper, we formulate distributed social dilemma by Game Theory. Furthermore, we consider distributed social dilemma as not one-shot game but iterated game because social dilemmas generally depend on decision making for a long period more than that for a short period. Each player tries to acquire the adaptive strategy throughout local interactions. We make use of Genetic Algorithms (GA) as evolutionary operations [5]. Although the strategies of players evolve by GA in social dilemma, generally it is more difficult for players to cooperate each other than in Prisoner's Dilemma. The reason is that players cannot know who defects and cannot punish only defecting player in social dilemma game. Therefore, there are no strategies that be able to punish only defecting players and then come back to cooperation each other, for example tit for tat (TFT).

The most characteristic point of distributed social dilemma is the game selection of players. Basis of this characteristics, players can acquire the countermeasure against defecting players that is, players leave the game with defecting players. The reason is that, if only cooperating players leave the game with defecting players, defecting players cannot free ride cooperating players and their payoffs decrease. Therefore, in distributed social dilemma there is the implicit punishment to defecting players.

In this paper, our purpose is to examine how the game selection of players influences the evolution of cooperation in distributed social dilemma. that is, whether players acquire the adaptive strategies to the game selection. In order to examine, we make use of agent-based simulation that each agent is regard as player [1, 5, 6, 7]. In agent-based simulation, we observe the transitions of the number of cooperative players and free riders in each game and the game selection of players.

2 Distributed Social Dilemma

2.1 Basic Structures

Basic strictures of distributed social dilemma are summerize below. Suppose that n is the number of players and m is the number of social dilemma games.

Player Set

$$N = \{1, .., i, .., n\} \quad (1)$$

Strategy Set of Player i

$$\Pi_i = \{S_j, \overline{S_j} \mid j = 1, ..., m\} \quad (2)$$

S_j : Cooperate in game j
$\overline{S_j}$: Defect in game j

Payoff Function Set of Players

$$F = \{f_1, ..., f_m\} \quad (3)$$

Payoff Function f_j of Player i of Game j
$|S_j|$: number of players selecting Cooperate in game j
$|\overline{S_j}|$: number of players selecting Defect in game j

	$\frac{B}{mD} \le \frac{\lvert S_j\rvert}{\lvert\overline{S_j}\rvert+\lvert S_j\rvert}$	$\frac{B}{mD} > \frac{\lvert S_j\rvert}{\lvert\overline{S_j}\rvert+\lvert S_j\rvert}$
S_j	$\alpha - m\frac{\lvert S_j\rvert}{\lvert\overline{S_j}\rvert+\lvert S_j\rvert}D - B$	$\alpha - mD$
$\overline{S_j}$	$\alpha - m\frac{\lvert S_j\rvert}{\lvert\overline{S_j}\rvert+\lvert S_j\rvert}D$	$\alpha - mD$

Table 1 payoff function f_j of player i of game j

According to the basic structures, if the ratio of cooperating players $\frac{|S_j|}{|S_j|+|\overline{S_j}|}$ in social dilemma game j is over the threshold $\frac{B}{mD}$, the payoff of cooperating players in this game is more than the payoff in which all players defect. In this paper, basis of these game structures, the term "collective cooperation" is defined as the situation that the ratio of cooperating players is the threshold.

2.2 One-Dimensional World Model

In our research, each social dilemma game is in one-dimensional world [7]. Thus there are one-dimensional worlds as many as social dilemma games. As the ends of a one-dimensional world are pasted together, a consequence each lattice has adjacent lattices to the right and to the left. Fig.1 gives lattices for one-dimensional world. All lattices are occupied by individual players and there are no blank lattices. Players in a world play same game with all individual players simultaneously. With regard to spatial locality, we define neighborhoods in one-dimensional world. Now n lattices to the left and to the right define as neighborhoods. Players can know only neighborhood decisions. Fig.2 shows one example of neighborhood in one-dimensional world.

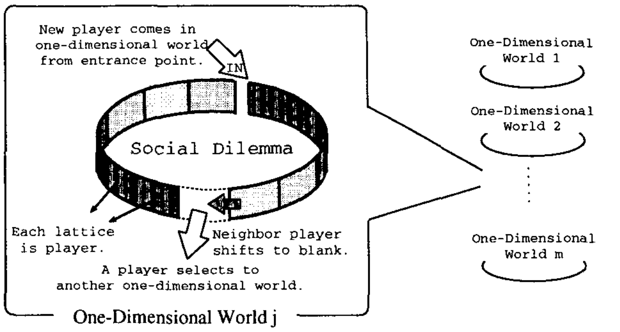

Fig. 1: Outline of one-dimensional world: Player selecting one-dimensional world j from other worlds comes in fixed entrance point. When lattice becomes blank because player selects another world, neighbor player shifts to blank

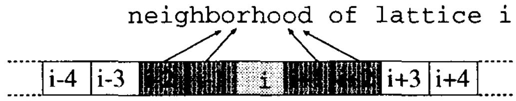

Fig. 2: Example of neighborhood in one-dimensional world: Next two lattices of lattice i to the right ($i+1$,$i+2$) and the left ($i-1$,$i-2$) are defined as neighborhood.

3 Evolution of Strategy

3.1 Decision Making

A player determines the strategy, that is, cooperate or defect and the game it plays, based on the history of interaction among players [3]. Each player has a strategy string that dictates its strategy for playing the game. Player makes decision based on a memory of the outcomes of the last two games played that it is called a memory length of size 4. History contains the decisions of itself and the decisions of neighborhood of last two games. The result of decisions of neighborhood of player is recorded as the ratio of cooperate to defect of neighborhoods of player. If the ratio is over the threshold, the result of decisions of neighborhoods is recorded as C in history, and if the ratio is not over, the result is recorded as D. In order to decide cooperate or defect, the strategy sting provides a response for every possible situation that could arise from a memory length of 4, that is 16 possible situations, where a response is encoded as '1' for cooperate and '0' for defect. Similarly, in order to decide the game it plays, a response is encoded as from '1' for playing game 1 to 'm' for playing game m. The strategy string provides appropriate responses for when player first arrives a new game, that is, either always cooperate or always defect, decision where player starts a new game, that is, either always start in same place (1bit), and for the second game that is what do play following CC, CD, DC or DD (4bits). The strategy string for decision of cooperate or defect is 21 long to cover all possible situation. Similarly, the strategy string of game selection is also 21 long. Therefore, in total strategy string is 42 long.

3.2 Evolutionary Operation

At the end of iteration of distributed social dilemma game, the current population is transformed into a new population of the same size through GA [4]. In each one-dimensional world, crossover and mutation are operated to the strategy strings of players. A population exists in each one-dimensional world, which is the set of players that select same world at the end of iteration. At the beginning of the genetic step, all players select the player with best fitness from neighborhoods as partner. In genetic operations, fitness is equal to its average payoff. The range of neighborhood for genetic operations is equal to that of perception of another cooperating and defecting players as fig.2. And then, two-point crossover is accomplished between the player and the partner to obtain the strategy string for one offspring. After crossover of all players, each offspring is subjected to two kinds of mutation with a certain probability. One is the mutation to the part of the next decision represented in '1' or '0' is accomplished to flip one bit. The other is the mutation to the part of the next game represented in '1' $\sim$ 'm' is accomplished to turn one bit to another number randomly.

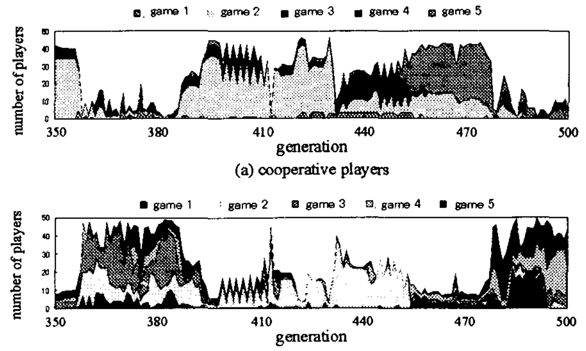

Fig. 3: The transition of the number of cooperating players and defecting players: (a) the transition of the number of cooperating players, (b) the transition of the number of defecting players in each game.

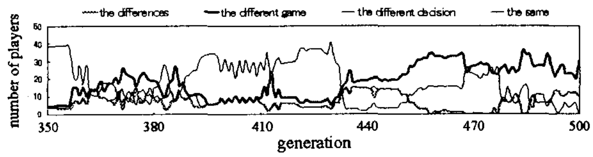

Fig. 4: The transition of the number of the players selecting the different behavior compared with the last game.

4 Simulation

4.1 Conditions

In order to analyze evolution of cooperation in distributed social dilemma from point of view of game selection of players, we observe the transitions of the number of cooperating players and defecting players in each game and the number of players changing the game. The condition of the important parameters is shown in the following Table.2.

4.2 Result

We provide one example of the transitions in a certain trial from 350 generation to 500 generation. Fig.3 shows the transition of the number of cooperating players and defecting players. Fig.4 shows the transition of the number of the players selecting the different behavior compared with the last game. All players are classified into four parts in the selection of the decision and the game, that is, the same compared with the last game (the same decision and game), the different decision (and the same game), the different game (and the same decision) and the differences (the different decision and game).

number of players	$\|N\| = 50$
number of games	$\|M\| = 5$
number of generations	$G = 200$
number of iterations	$T = 200$
number of neighborhoods	$\|Neighbor\| = 7$
coefficient of payoff function	$B = 160$
coefficient of payoff function	$D = 2$
coefficient of payoff function	$\alpha = 400$
coefficient of payoff function	$\alpha = 400$
crossover rate	$R_{crossover} = 0.99$
mutation rate	$R_{mutation} = 0.1$

Table 2: The important parameters in the simulations.

Here, we observe the transitions when collective cooperation is formed, that is, from 380 generation to 480 generation espesially. From 380 generation to 430 generation, however there is one sudden dip and two styeep rise of cooperative players in game 2, cooperative players in game 2 fluctuate between 20 and 30. In this period, The players selecting the same is steady at about 30. The players selecting the different decision, the different game and the differences are almost equal at 7.

From 430 generation to 455 generation, there are about 25 cooperating players in game 1,2 and 4 and about 25 defecting players in game 2. In this period, The players selecting the same is steady at about 22. The players selecting the different decision and the different game and the differences are almost equal at 12. The players selecting the same is about 4.

From 455 generation to 480 generation, there are about 25 cooperating players in game 2 and about 12 cooperating players in game 4. Defecting players in each game, almost 10 altogether, are steady. In this period, The players selecting the different game is steady at about 32. and the players selecting the same is steady at about 17. the player selecting the different game and the differences are almost equal few.

5 Discussion

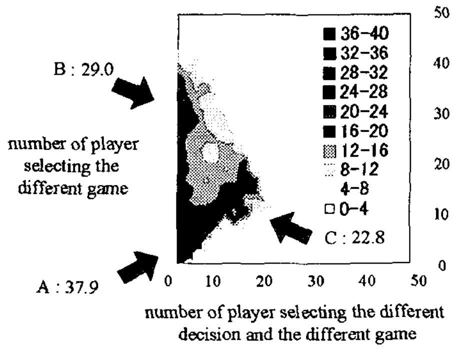

Fig. 5: The relation of the average number of cooperative players, the number of the players selecting the different game and the number of the players selecting the different decision and the different game compared with last game. The points A, B and C represent that there are more cooperative players than its neighbors.

In the simulation, collective cooperation is remarkable in following three cases. First, from 92 generation to 118 generation, most players select the same. Secondly, from 135 generation to 148 generation, most players select the different game and selecting the same. Finally, from 154 generation to 170 generation, most players select the different decision or the different game or the differences and few players select the same. In order to examine how the game selections of players influence the evolution of cooperation, we analyze the relation of the number of cooperative players and the number of the players selecting the different game and the players selecting the different decision and the different game.

We calculate the average number of cooperative players in 20 trials. In Fig.5, the x axis is the players selecting the different game and the y axis is the players selecting the differences. The shading represents the average number of the cooperative players. In fig.5, The point A is the situation that the average number of cooperative players is 37.9 when the players selecting the different game and players selecting the differences are few. The point B is the situation that the average number of cooperative players is 29.0 when the players selecting the different game is about 32 and the players selecting the differences are few. The point C is the situation that the average number of cooperative players is 22.8 when the players selecting the different game and the players selecting the differences are about 12.

As fig.5 indicates, the number of the players selecting the different game influences the number of cooperating players because there are cooperating players in addition to the point of A. Because cooperating players are more than its neighbors in the points of both B and C, cooperative players may increase inspite of the players selecting the different game and the differences. Therefore, we confirm that it is possible to increase cooperating players by the introduction of the game selection of players. In this research, because fig.5 is based on the average value of one generation, it is not clear how offen individual players select the different game and how individual players are divided in the game selection in iterated game in each generation. In this paper, we discuss collective cooperation as macro behavior but we lack of the obsevation in the idea of local interaction with the strategy strings. Thus, in order to analyze the evolution of cooperation in distributed social dilemma more precisely, it is nessesalry to concentrate our focus on major strategy strings, the distribution of them and the part used more often in them.

6 Conclusion

We propose "Distributed Social Dilemma" to represent the situation that players can select one game out of some social dilemma games. We formulate distributed social dilemma by Game Theory and make use of agent-based simulation. We make use of GA as evolutionary operations to acquire the adaptive strategy throughout local interactions. On the basis of simulation, we confirm that it is possible to increase cooperating players by the game selection of players.

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