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Uncovering cooperative behaviors with sparse historical behavior data in the spatial games

Xu-Wen Wang [a,b], Luo-Luo Jiang [c,*], Sen Nie [a,b], Bing-Hong Wang [b,c,d]

[a] School of Electrical and Electronic Engineering, East China Jiaotong University, Nanchang, Jiangxi 330013, China
[b] Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China
[c] College of Physics and Electronic Information Engineering, Wenzhou University, Wenzhou, Zhejiang 325035, China
[d] School of Science, Southwest University of Science and Technology, Mianyang, Sichuan 621010, China

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ABSTRACT

For past decades, the main attention of the evolutionary games has been focused on cooperation mechanism with the assumption that the strategy information of all players are known. However, it is difficult for observers to obtain the global information of players' strategies in the real world, and some players even hide their strategy information to confuse their opponents. Here we try to solve the problem to predicate the hidden strategies with sparse historical behavior data in the evolutionary games. To quantify the similarity of strategies among the players in our method, the Euclidean distance of players is defined from the strategies of the players in the few past rounds. Then, the hidden strategy of a player will be determined from the tendency that players with minimum Euclidean distance will adopt similar strategies. The method has good performance on determining hidden strategy of human beings in both the prisoner's dilemma game and the public goods game where strategies of twenty five percent players are hidden, and the success rate to determine hidden strategy reaches up to 0.9. It is also found that the success rate to determine hidden strategy depends on both length of historical behavior data and tempting payoff b (the prisoner's dilemma game) or multiple factor r (the public goods game).

1. Introduction

Cooperation is ubiquitous in biological and social systems, and understanding the emergence and maintenance of cooperative behaviors is still a major challenge [1–4]. Recent years, with the development of complex networks, the cooperation behaviors on networks have been investigated widely [5–8]. The prisoner's dilemma games [9–13], the snowdrift games [14,15] and the public goods games [16–18] are paradigmatic models to study the cooperative behaviors among selfish players. Several mechanisms, such as, aspiration-induced reconnection mechanism [19], punishment [20–23] and reward [24,25], social diversity [26,27], conditional strategies [28,29], information sharing [30,31], and games on interdependent networks [32–34] have been proposed to reflect the real systems.

Together with theoretical researches, previous studies on economic game experiments conducted in a small population also followed the assumption that strategy information of players are known. However, in real conditions with a large population, we usually know the strategy information of a fraction of players in current round, while the others are unknown [35]. A question

* Corresponding author. Tel.: +86 18267788986.
E-mail address: jiangluoluo@gmail.com (L.-L. Jiang).

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rises whether the hidden strategy information of a player can be determined from historical behavior data, even we do not know any information of the players such as payoffs in the former steps and the current round. Selfish players adopt strategies trying to maximize their payoffs in the next step, and the information of the past period obtained from the known players may reveal the tendency of the information on collective behaviors.

The players who have similar cooperation environments usually trend to have similar strategy sequences. Especially, for longer strategy evolution, two players have similar strategy sequences at the beginning will adopt the same strategy in the next steps with larger probability. Therefore, we can obtain the hidden strategy of players from their similar players whose current strategies information is known. In this paper, we introduce a method to predict the strategies of unknown players based on the former strategy selection. It is assumed that the strategies of the former L_e time steps for all players are known, then, we define the Euclidean Distance to quantify the similarity of strategies among the players. Once we have obtained the information of strategy distance from the former behaviors, the strategy of a unknown player will adopt in time step t $(t > L_e)$ trends to be the same as the one whose Euclidean Distance with itself is minimum. The prisoner's dilemma games (PDG) and public good games (PGG) are used to test the feasibility of the method, and the evolutionary rule for strategy adoption is Fermi equation where the strategy of a player be adopted by others is depending on the difference between its payoff and others payoffs. The results show that for both of two models, the method can predict the player's strategy more accurately, even we have a little amount of sample.

The paper is organized as follows: In Section 2, we describe the method be introduced to predict the strategies of unknown players for both of two update rules, as well as the method to predict the evolution of frequency of cooperators. The numerical results and analysis of the method are presented in Section 3. Finally, the conclusion is presented in the Section 4.

2. Results

2.1. Model

In this paper, both models of PDG and PGG are investigated in the condition of some behavior data hid. All players are located on a $L \times L$ square lattice with period boundary condition, who adopt either as a cooperator with strategy $s_x = C$ or a defector $(s_x = D)$ with equal probability. (i) In PDG, the player can choose either as a cooperator or defector, they both receive payoff R upon mutual cooperation and P upon mutual defection. If one defects while the other cooperates, the cooperator receives S while the defector gets T. The ranking of the four payoff values is $T > R > P > S$. Thus, in a single round of the PDG, it is best to defect regardless of the opponent's decision. Following common practice[9], the parameter $T = b(1 < b < 2)$, $R = 1$, and $P = S = 0$, where b is the only payoff parameter representing the temptation to defect. At each time step, individual i plays the PDG game with its four neighbors, its payoff is the sum of all the payoffs acquired from its neighbors. (2) For PGG, each player is arranged as a cooperator or defector, cooperators contribute a cost c to the public good and defectors do nothing. The total reward is the product between the total contribution and an enhancement factor r, which is equally distributed among all members in the group.

Given the total payoffs from the previous round, the evolutionary update rule used in this paper is Fermi equation, that is the player x adopts the strategy with neighbor y's strategy with the probability[9]:

$$W(s_x \leftarrow s_y) = \frac{1}{1 + e^{[(P_{s_x} - P_{s_y})/K]}}, \tag{1}$$

where K quantifies uncertainty by strategy adoptions. We set the network size $N = 400$ and $K = 0.5$ for all simulations. The players update their strategies synchronously.

The prediction method is described as following steps:

(i) A fraction of f_s players are randomly selected as the sample, the strategies of these players are considered to be known. The other $1 - f_s$ players are treated as unknown, the strategies of these players' strategies at the beginning of L_e time steps are also known. Our goal is to predict these unknown players' strategies at last of 50 time steps in total 200 time steps.

(ii) We define a parameter $S(x, y)$ to quantify the similarity of the evolution of cooperation behaviors between individual x and y, the less $S(x, y)$ indicates that the two players have more similarity in the cooperation behaviors. For player x, once we have already obtained the S between x and all of sample players, the strategy of x will adopt in the next time step is the strategy of player who has the minimum Euclidean Distance with it. The parameter $S(x, y)$ is obtained by:

$$S(x, y) = \sqrt{\sum_{i=1}^{L_e} (s(x_i) - s(y_i))^2}. \tag{2}$$

Where the $s(x_i)$ denotes the strategy of player x adopt at the time step of i.

(iii) If the predicted strategy of player x is the same as the actual strategy of x, we consider the prediction is success. Given a time step t, the success rate at t is averaged by all unknown players, and the final success rate is obtained by the average of last 50 time steps in the total 200 time steps.