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Heterogeneous preference selection promotes cooperation in spatial prisoners' dilemma game

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ABSTRACT

Adopting the strategy of neighbor who performs better is crucial for the evolution of cooperation in evolutionary games, in that such an action may help you get higher benefit and even evolutionary advantages. Inspired by this idea, here we introduce a parameter α to control the selection of preferred opponents between the most successful neighbor and one random neighbor. For α equaling to zero, it turns to the traditional case of random selection, while positive α favors the player that has high popularity. Besides, considering heterogeneity as one important factor of cooperation promotion, in this work, the population is divided into two types. Players of type *A*, whose proportion is v, select opponent depending on the parameter α, while players of type *B*, whose proportion is $1 - v$, select opponent randomly. Through numerous computing simulations, we find that popularity-driven heterogeneous preference selection can truly promote cooperation, which can be attributed to the leading role of cooperators with type *A*. These players can attract cooperators of type *B* forming compact clusters, and thus lead to a more beneficial situation for resisting the invasion of defectors.

1. Introduction

Understanding the maintenance and emergence of cooperation is a fundamental puzzle for social scientists, evolutionary biologists and statistical physicist. According to Darwin's theory of nature selection [1], this altruistic behavior will be easily invaded by selfish defectors, causing a tragedy of commons [2]. Aiming to this problem, evolutionary game theory provides a unifying mathematical framework [3–6], especially the prisoner's dilemma game (PDG). It is frequently used to capture the essential social poverty between self-interest and collective benefits [6,7]. In its original model, two players must make a choice between cooperation (C) or defector (D) simultaneously. Mutual cooperation (mutual defection) yields a reward *R* (punishment *P*). If one defector meets a cooperator, the former can get the temptation to defect *T*, the latter will receives the suckers' payoff *S*. These payoffs are strictly satisfy the ranking $T > R > P > S$ and $2R > T + S$. Obviously, defection is a best choice regardless what the opponent choose, which is inconsistent with the ubiquitous cooperative phenomenon in our daily life.

Over the past decades, a variety of scenarios have been proposed to solve the above social dilemma [8–15]. Of great interest, Nowak classified all these scenarios to five mechanisms: kin selection, direct and indirect reciprocity, group selection and network reciprocity [16]. Among these mechanisms, network reciprocity [17] has received much attention and inspired many scholars to investigate this issue via spatial structure, in which cooperators can form compact clusters on the structured network to protect the interior from being exploited by defectors. In line with this pioneering work, a variety of works aiming to probe the evolution of cooperation via different network topologies such as small-world network, ER graph, BA scale-free network, Multilayer coupling network, to name but a few [18–21]. Besides, different factors have also been considered in structured population for exploring its impact on the evolution of cooperation, for example, different coevolution setup [22], reputation [23], different evolutionary dynamics [24], and so on.

At present, preference selection has received much attention and has been proved to be an efficient way for promoting the evolution of cooperation [25–27]. In addition, it has been also been verified that in structured population spatial heterogeneity can promote cooperation both in theoretically and empirically [28–30]. Thus, an interesting question appears: if we couple the heterogeneous and preference selection in structured population together, does this setup promote cooperation? In detail, following the work of Zhang et al. [26], this work is classified the population into two types, denoted by type *A* and type *B*, respectively. While players of

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type A select his opponent depending on the parameter α, players of type B select his opponent at random irrespective of parameter α and their initial strategies. Besides, the proportion of the aforementioned two types of players are denoted by v (type A) and $(1-v)$ (type B) and remains unchanged during the simulations. The rest of this paper are organized as follows: we first describe our modified model of PDG; subsequently, the main simulation results are shown in Section 3; last, we summarize our conclusions in Section 4.

2. Methods

In our work, each player is designed as either a cooperator (C) or defector (D) with equal probability. Besides, two types of individuals (A (B)) are distinguished and the division of these players is performed with the probability v and $1-v$. This is a uniform and random distribution irrespective of their initial strategies and keeps constant during the simulations. As for interaction network, we choose $L \times L$ square lattice with four direct neighbors. For simplicity but without loss of generality, we choose weak PD game with rescaled matrix: $R=1$, $P=S=0$, and $T=b$ $(1<b<2)$, and thus we capture the essential social dilemma between individual and social welfare.

The game is iterated forward in accordance with the Monte Carlo simulation procedure comprising the following elementary steps. First, a randomly selected player x gets his payoff P_x by playing the game with his direct neighbors (the payoffs of all the neighbors of player x are calculated in the same way). Next, we select one neighbor y with the probability:

$$\Pi_y = \frac{exp\ (w_y * S_y)}{\sum_z exp\ (w_z * S_z)}, \tag{1}$$

where the sum runs over all the neighbors of player x. Importantly, w_x is the so-called selection parameter that depends on the type of player x according to

$$w_x = \begin{cases} \alpha, & if\ x = A \\ 0, & if\ x = B \end{cases}. \tag{2}$$

In addition, S_x represents the popularity of player x and its definition is as follows:

$$S_x = \frac{n_x + 1}{k_x + 1}, \tag{3}$$

where n_x is the number of neighbors that have the same strategy with focal player x and k_x is the degree of player x. Obviously, if the selection parameter $\alpha = 0$ then irrespective of v the traditional game is recovered [31]. However, when $\alpha > 0$ and $v > 0$, we introduce a preference selection in all players of type A, namely the focal player x can adopt the strategy of those neighbors who have a higher popularity. Lastly, player x tries to adopt the strategy of the selected neighbor y with the following probability depending on the payoff difference,

$$W = \frac{1}{1 + \exp[(P_x - P_y)/K]}, \tag{4}$$

where K denotes the amplitude of noise or its inverse the so-called intensity of selection, since the effect of K has been extensively investigated [32,33], we simply fix the value of K to be $K=0.1$ in this work.

During one full Monte Carlo step (MCS) each player has a chance to adopt one of the neighboring strategies once on average. Results of Monte Carlo simulations presented below were obtained on 100×100 lattices, besides, we have also tested our results in larger sizes of the lattice and got the same results. Key quantity the fraction of cooperators ρ_c was determined within the last 5×10^3 full MCS over the total 5×10^4 steps. Moreover, since the heterogeneous preference selection of neighbors may introduce additional disturbances, the final results were averaged over up to 100 independent realizations for each set of parameter values in order to assure suitable accuracy.

3. Results

It is instructive to first examine the influence of parameter α (left) and v (right) on the evolution of cooperation. Fig. 1(a) presents how ρ_c varies in dependence on the temptation to defect b for different values of parameter α. When $\alpha = 0$, it will return to the traditional game, in which cooperators soon die out. While $\alpha > 0$ contains a preference selection in all types of player A. In this case, the evolution of cooperation can be promoted remarkably, in addition, cooperators even prevail over a larger interval of b. Fig. 1(b) depicts the fraction of cooperation in dependence on the temptation to defect b when $\alpha = 3$ and v varies. It can be also observed that, compared with the traditional game (v), positive v not only enable cooperators to reach their exclusive dominance, but also emerge when b lies between [1, 1.105]. However,

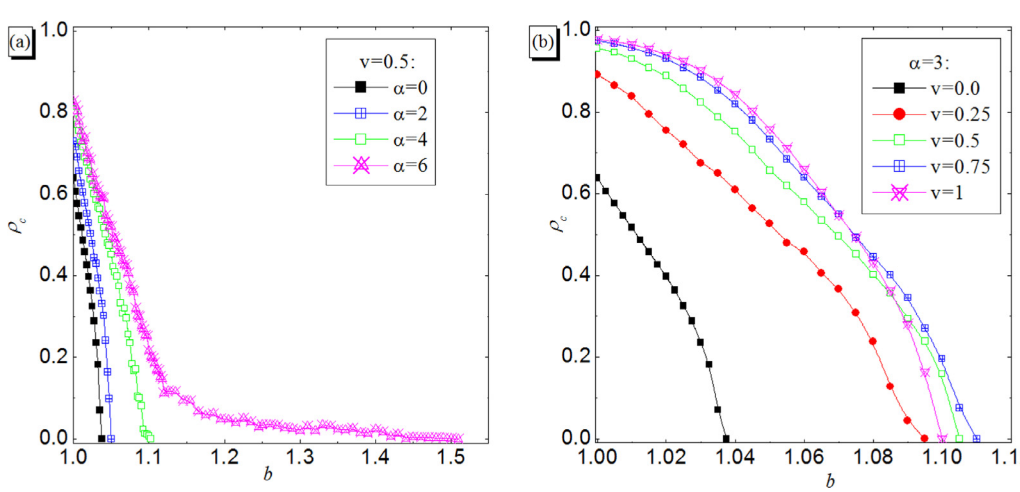

Fig. 1. (a) The fraction of cooperation in dependence on the temptation to defect b for different values of α, we fix $v = 0.5$. Comparing to the traditional game ($\alpha = 0$), the preference selection parameter α can truly promote the evolution of cooperation. (b) The fraction of cooperation in dependence on the temptation to defect b when $\alpha = 3$ and v varied. It can be observed that the parameter v can enable cooperators to reach their exclusive dominance when b is relatively small. However, when b exceeds 1.08, there is a optimal v that can best promotes cooperation. Depicted results are obtained for $K = 0.1$.