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Asymmetric learning ability promotes cooperation in structured populations

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ABSTRACT

In this paper, we consider an asymmetric learning ability in structured population. The rate of strategy adoption from one randomly neighbor is controlled by the payoff difference and a factor α. Players of type B will think over α ($\alpha > 1$) times when he decides whether to adopt his opponent's strategy. While players of type A just consider only once. The concentration of players A and B are denoted by v and $1-v$ and remains unchanged during the simulations. Through numerous computing simulations, we find that our new setup of asymmetric learning ability can promote the evolution cooperation in the spatial prisoner's dilemma game. Furthermore, in order to explore the generality of this finding, we have tested the results on spatial public good games and random regular graphs.

1. Introduction

Cooperation is ubiquitous in nature, ranging from human daily life, biological, to economical systems. Network reciprocity, proposed by Nowak and May [1,2], has been verified to be a powerful framework to study the evolution of cooperation. Along with this framework, a variety of factors aiming to probe the evolution of cooperation has been considered. Such as, aspiration [3,4], reputation [5,6], reward and punishment [7–10], social diversity [11,12], asymmetric [13–15], coevolution setup [16], loner [17], different network topology [18–20].

Teaching and learning ability, as an important feature of individuals, has been extensively investigated in the content of evolutionary games. Szolnoki et al. study the quenched inhomogeneous distribution of teaching activity in evolutionary dynamics [21]. Wu et al. study the diverse roles of reduced learning ability of players in the evolution of cooperation [22]. Tanimoto et al. show their understanding about network reciprocity by considering the coexisting learning and teaching strategies [23]. In real world, the learning or teaching ability of individuals may exhibit some heterogeneous instead of homogeneous. As stated in Ref [11], the dramatic improvement in the maintenance of cooperation is observed when considering an evolutionary PD game on scale-free structures at a low noise level. One may ask: how cooperation fares if we consider an asymmetric learning ability. It is worth mentioning that, different from previous existing literature [21–23], here, we proposed a new asymmetric setup of learning ability and defined as follows. Two types of players are distributed randomly on a structured population. Here, we denoted as type A and type B, respectively. Players of type B will think over α ($\alpha > 1$) times when he decides whether to adopt his opponent's strategy. While players of type A just consider his/her decision only once. Since the probability of update strategy is less than 1. The more the person thinks, the less he has the learning ability. Based on this fact, We denote that someone who make repeat thinking when he update his strategy is a player that possess lower learning ability, and vice versa. In addition, the concentration of players A and B are denoted by v and 1-v and remains unchanged during the simulations.

The rest of this work is organized as follows: we first describe our new setup; subsequently, the main simulation results are shown in Section 3; last, we summarize our conclusions in Section 4.

2. Methods

The evolutionary games are staged on a square lattice or random regular graphs with periodic boundary conditions. Each player is designed either as a cooperator or defector with equal probability and has four direct neighbors. The weak prisoner's dilemma game is characterized by the temptation to defect $T = b$, Reward for mutual cooperation $R = 1$, the punishment for mutual punish-

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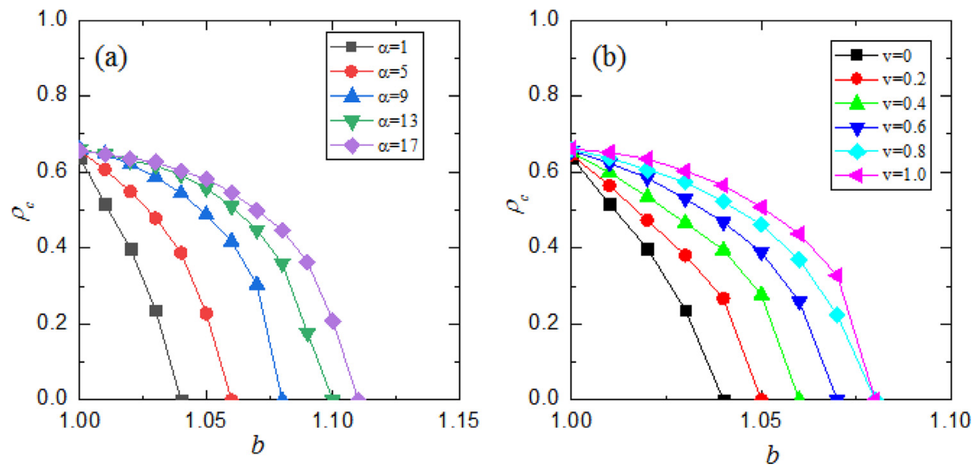

Fig. 1. (a) Fraction of cooperation ρ_c as a function of the temptation to defect b for different values of parameter α, we fix $v=0.8$. (b) The fraction of cooperation independence on the temptation to defect b when $\alpha = 8$, and v varied. The results are obtained on square lattice.

ment P as well as suckers' payoff S equaling 0. Where $1<b<2$ and $2R>T+S$ promise a proper payoff ranking. For the public goods game, each player will participate G different groups. In each group, cooperators contribute 1 to the public good, while defectors contribute nothing. The sum of contributions is subsequently multiplied by the enhancement factor r and then equally shared amongst the G group members. Here the total payoff of a player is the sum of payoffs from all the G groups where he belong to.

The game is iterated forward in accordance with the Monte Carlo simulation procedure comprising the following steps. First, a randomly selected player x get his payoff P_x by playing the game with all his neighbors. Next, one randomly selected player, say y, also acquired his payoff P_y in the same way. Lastly player x will adopt the neighbor's strategy with a probability depending on the payoff difference.

$$W = \left(\frac{1}{1+\exp\left[\frac{P_x-P_y}{K}\right]} \right)^{M_x}. \tag{1}$$

where K denotes the amplitude of noise [24,25]. The power M_x is given as

$$M_x = \begin{cases} \alpha, & if\ x \in B, \\ 1, & if\ x \in A, \end{cases} \tag{2}$$

where the value of α characterized the strength of reduced learning activity of player x. When $\alpha = 1$, the system will fall into homogeneous case where traditional version is recovered. While $\alpha > 1$ lead the system have the heterogeneous feature. In fact, there are many real life examples to support our asymmetric setup about learning ability. For example. In stock market, some prudent investors will think over and over again before he make his final choice. Some confident investors, however, make their decisions very quickly.

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. 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 10 independent realizations for each set of parameter values in order to assure suitable.

3. Results

For easier interpretation, we first present results for the most traditional setup, where the square lattice and the weak prisoner's dilemma game is considered. Fig. 1(a) shows how cooperation varies in dependence on the temptation to defect b for different values of α when $v=0.8$. For $\alpha = 1$, it will turn to the traditional version, where cooperation will go extinct at $b=1.0375$. $\alpha > 1$, however, enable the players have the heterogeneous learning ability. In this case, cooperation can be remarkably promoted compared with the traditional version. Especially, the larger the value of α, the larger the value of threshold, where cooperation dies out. Fig. 1(b) depicts the fraction of cooperation in dependence on the temptation to defect b when $\alpha = 8$ and v varied. Clearly, we can find a similar result as in Fig. 1(a). when the fraction of players that have the lower learning ability become large, the cooperation will be enhanced obviously compared with the traditional game where the system has no players possess the reduced learning ability. In a word, our new setup has beyond the scope of traditional network reciprocity and in what follows, we will present results in favor of the robustness of this observation, as well as results that explain it.

It well-known that cooperation is affected by the different type of interaction network, where in particular the scale free network has been proved to be a potent promoter of cooperation. Besides, some properties of interaction networks, such as clustering coefficient and the average degree of players have also been identified as being decisive. Subsequently, we test the robustness by replacing the square lattice with the random regular graph in Fig. 2. Results presented are qualitatively identical to our observation in Fig. 1. As expected, taking into account the asymmetric learning ability of players has virtually an identical influence on the evolution of cooperation despite there are some tiny difference between the results of random regular graph and square lattice. Thereby, we have come to the fact that the reported observation is independent of the topologies of the interaction network.

Besides different topologies, the results governed by pairwise interactions and group interactions also play a crucial role, as reviewed by [26]. With this aim, we going further explore the robustness of our findings by replace the prisoner's dilemma game with the public goods game. As illustrated in Fig. 3. Too the evolution of public investment is evaluated when the asymmetric learning ability is considered, the promotion effect, however, is less striking when the degree of asymmetric continues to increase. In fact, this is due to the intrinsic growth rates of both cost and the