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Voluntary strategy suppresses the positive impact of preferential selection in prisoner's dilemma

Lei Sun [a,b], Pei-jie Lin [b,*], Ya-shan Chen [a]

[a] Zhicheng College, Fuzhou University, Fuzhou 350002, PR China

[b] Department of Physics, Fuzhou University, Fuzhou 350108, PR China

HIGHLIGHTS

- We investigate the system behavior of prisoner's dilemma game (PDG) with voluntary participation extension on regular lattices.
- We show that aspiring to the most successful neighbor (for positive value of w) can promote cooperation in voluntary PDG for small b.
- We show that for negative values of w, all the cooperators, defectors and loners can coexist on the lattices.

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ABSTRACT

Impact of aspiration is ubiquitous in social and biological disciplines. In this work, we try to explore the impact of such a trait on voluntary prisoners' dilemma game via a selection parameter w. $w = 0$ returns the traditional version of random selection. For positive w, the opponent of high payoff will be selected; while negative w means that the partner of low payoff will be chosen. We find that for positive w, cooperation will be greatly promoted in the interval of small b, at variance cooperation is inhibited with large b. For negative w, cooperation is fully restrained, irrespective of b value. It is found that the positive impact of preferential selection is suppressed by the voluntary strategy in prisoner's dilemma. These observations can be supported by the spatial patterns. Our work may shed light on the emergence and persistence of cooperation with voluntary participation in social dilemma.

1. Introduction

In evolutionary biology and social science, the emergence and maintenance of cooperation is an open question under the temptation of higher self-interest [1–3]. Evolutionary game theory, providing a theoretical framework to explain the origin of this phenomenon, has stimulated extensively studies from a variety of disciplines in the last few years [4–6]. Among all the forms of games, the most commonly used game for demonstrating the social cooperation and conflict is the prisoner's dilemma game (PDG), which is attracting considerable attentions in the theoretical and experimental researches. In the original PDG [7], two players can only adopt one of the two available strategies: cooperation (C) of defection (D). Both players received a reward R for mutual cooperation and a punishment P for mutual defection. If one cooperates but the other defects, the defector gets the payoff T, while the cooperator gets S ($T > R > P > S$). In reality, to avoid deadlocks in states of mutual defection, voluntary participation is considered as one effective approach [8], where a third strategy: the loner strategy (L) is adopted in addition to cooperation (C) and defection (D). The risk averse loners would rather rely

* Corresponding author. Tel.: +86 13599044382.
E-mail address: linpeijie@fzu.edu.cn (P.-j. Lin).

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on some small but regular income than participate. Recently, it is reported that the voluntary participation in the PDG [8] may provide an escape hatch out of economic stalemate and results in a substantial willingness to cooperate even in sizable groups, in the absence of repeated interactions.

Beside voluntary behavior, spatial structured population has been widely investigated in the framework of game theory. Up to now, much attention has been given to the evolutionary games on several population relations, including on regular networks [9–15] and on complex networks [16–20]. More interestingly, many realistic phenomena are also introduced into evolutionary games, such as, reputation mechanism [21–23], preferential selection [24,25], the influence of environment factors [26–28], heterogeneous activity [29–32], success-driven migration [33] and individual age structure [34,35]. In recent years, various types of mechanisms have been studied to characterize actual contacts in population and interpret that how cooperative behavior survives. In recent research papers [25,36], the propensity of designating the most successful neighbor as being the role model players is considered in the prisoner's dilemma game, where players were aspired to the fittest by introducing a single parameter w, and find that increasing the probability of adopting the strategy from the fittest player within reach, setting w positive, promotes the evolution of cooperation.

Inspired by these successful research works, an interesting question was raised, and which is also what we are going to study. In other words, if we consider voluntary participation in the prisoner's dilemma game, which allows partners to aspire to the fittest, that is, the introduction of the most successful neighbors as specified role to be imitated, will it be constructive for cooperation in the evolution? It is obviously the defectors have higher fitness due to their high income, so what we assume might lead to a faster spreading for defectors. In early studies, Nowak et al. [37] showed that increasing probability to learn from the fittest neighbors strengthens cooperation, but this relation is not monotonic in the whole range of parameters. Here, our goal is to further investigate strategy frequencies in the voluntary PDG and to explain the reported results.

Here, we study Prisoner's Dilemma considering voluntary participation which allows players to aspire to the fittest. We study this mechanism in affecting the evolution of cooperation in a square grid. In our modified prisoner's dilemma, this simple mechanism can contribute to the evolution of cooperation significantly in different interactive network by the computer simulations we have demonstrated. Unlike the prediction of two-strategy setup, the effect of preferential selection is largely impeded during the voluntary PD. This article is in the following orders: first we will describe the evolutionary game with voluntary participation. Then we present the main results and interpret the observed phenomena, and finally come to our conclusions.

2. Model

We consider a voluntary prisoner's dilemma game with the temptation to defect $T = b$ ($1 \le b \le 2$) which is the highest payoff received by a defector if playing against a cooperator, reward for mutual cooperation $R = 1$, the punishment for mutual defection $P = 0$, and the sucker's payoff $S = 0$ which is the lowest payoff received by a cooperator if playing against a defector. The loners refuse to participate and rather rely on some small but fixed income σ. Then the payoff matrix is the following form:

$$P = \begin{bmatrix} & C & D & L \\ C & 1 & 0 & \sigma \\ D & b & 0 & \sigma \\ L & \sigma & \sigma & \sigma \end{bmatrix}. \tag{1}$$

As the interaction network, all players are arranged on a rigid regular $L \times L$ lattice with periodic boundary conditions and interact with their four nearest neighbors. In the voluntary PDG, each player adopts one of three strategies: defection D, cooperation C, or loner L, as indicated by a state variable $s(x) \in \{C; D; L\}$. The game is iterated forward in accordance with the sequential simulation procedure comprising the following elementary steps. First, player x acquires its payoff p_x by playing the game with all its neighbors. Next, we evaluate in the same way the payoffs of all the neighbors of player x and subsequently select one neighbor y via the probability

$$\prod_y = \frac{\exp(wp_y)}{\sum_z \exp(wp_z)} \tag{2}$$

where the sum runs over all the neighbors of player x and w is the newly introduced selection parameter. Evidently, setting w equal to 0 returns to the most frequently adopted situation where player y is chosen uniformly at random from all the neighbors of player x. For positive values of w, however, Eq. (2) introduces a preference to copy the strategy of those neighbors of player x who have a higher payoff p_y. However, for negative values of w players with a lower payoff are more likely to be selected as potential strategy donors. Here it is worth mentioning that the selection of opponent (namely, the value of w) does not affect the updating process of strategy, since they are two independent steps. After the fixation of opponent, player x adopts the strategy sy from the selected player y with the probability

$$W(s_y \to s_x) = \frac{1}{1 + \exp[(p_x - p_y)/K]} \tag{3}$$