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Minireview

Diversity of neighborhoods promotes cooperation in evolutionary social dilemmas

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HIGHLIGHTS

- Diversity of individual's neighborhood promotes cooperation in networked population.
- The heterogeneous mechanism generates more obvious negative feedback mechanism.
- Middle heterogeneity guarantees the best environment of cooperation.

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ABSTRACT

Explaining the evolution of cooperative behavior is one of the most important and interesting problems in a myriad of disciplines, such as evolutionary biology, mathematics, statistical physics, social science and economics Up to now, there have been a great number of works aiming to this issue with the help of evolutionary game theory. However, vast majority of existing literatures simply assume that the interaction neighborhood and replacement neighborhood are symmetric, which seems inconsistent with real-world cases. In this paper, we consider the asymmetrical neighborhood: player of type A, whose factor is controlled by a parameter τ, has four interaction neighbors and four replacement neighbors, while player of type B, whose factor is controlled by a parameter $1-\tau$, possess eight interaction neighbors and four replacement neighbors. By means of numerous Monte Carlo simulations, we found that middle τ can make the cooperation reach the highest level While for this finding, its robustness can be further validated in more games.

Contents

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1. Introduction

The emergence and maintenance of cooperation not only commonly appear in human societies, but also ubiquitous in animal societies [1,2]. To explain these phenomena, evolutionary game theory has become a useful tool aiming to this issue [3]. In particular, two paradigmatic models, prisoner's dilemma game and the snowdrift game, have attracted much attention and have been studied frequently [4,5]. In the basic model, each player must simultaneously choose one strategy between cooperation (C) and defection (D). If both of them choose cooperation (or defection), they will get the reward R (or punishment P). However, if one cooperator meets one defector, the former gets sucker's payoff S, while the later gets temptation T. If the payoff ranking satisfy $T > R > P \geq S$ and $2R > T + S$, it will be the prisoner's dilemma game; while if the payoff ranking becomes $T > R > S > P$, it turns to the snowdrift game. It is obvious that, mutual defection and cooperation–defection pair optimizes the individuals' payoff in prisoner's dilemma and snowdrift games, although mutual cooperation could yield a higher collective benefit. Thus, the survival of cooperation seems to be still difficult.

Over the past decades, considerable attention has been paid to solve the above unfavorable outcome of social dilemmas and suggest the promotion mechanisms of cooperation [6–15]. All these mechanisms can be actually attributed to five mechanisms: kin selection, direct reciprocity, indirect reciprocity, network reciprocity, and group selection [16]. Among these mechanisms, network reciprocity, the spatial structure as a powerful mechanism to promote cooperation has been in-depth study [17–19]. In the pioneering work [20], players were arranged on a square lattice and obtained their payoffs by playing games with their direct neighbors, then cooperators could survive by means of forming compact clusters, which minimizes the exploitation of defectors and protects those cooperators located in the interiors of such clusters. Along with this seminal idea many different mechanisms supporting cooperation in network population have been extensively suggested. Typical examples include costly punishment [21–23], reputation [24,25], heterogeneous activity [26–39], mobility of players [40–43], or population density [44], partner selection [45], popularity [46], and multilayer networks [47–52], to name but a few. Besides, co-evolution, involving the joint adjustment of both strategy and strategy-updating rule or interaction topology, opens another new window for this realm. For example, motivated by vibrant advances in network growth and evolution [53,54], the subject has evolved into a mushrooming avenue of research that offers new ways of ensuring cooperation, the cooperative behavior could be greatly enhanced by the co-evolution setup of non-growth dynamic network model and death–birth dynamics based on tournament selection [55].

In spite of recent great progress, the role of asymmetric network topology receives little attention, which yet seems more widespread in real society. For example, students and teachers usually have different interaction scope; Persons with wider social circle and talent skill of communications have more chance of interactions than those with smaller social circle and weak skill of communications. To this aim, we research the prisoner's dilemma game and snowdrift game on asymmetric networks, where there exist two types of players: player of type A, whose factor is controlled by a parameter τ, has four interaction neighbors and four replacement neighbors, and player of type B whose factor is controlled by a parameter $1-\tau$, possesses eight interaction neighbors and four replacement neighbors. Interestingly, we find middle τ can guaranteed the best evolution of cooperative behavior.

2. Evolution game model and dynamics

We consider the evolutionary prisoner's dilemma and snowdrift games in this study. The evolutionary prisoner's dilemma game is assigned as follows: the temptation $T = b$ if one player defects while his opponent cooperates, reward $R = 1$ if both cooperate, and both the punishment $P = 0$ for mutual defection as well as the sucker's payoff $S = 0$. As a standard practice, $1 < b \leq 2$ ensures the ranking of payoffs must satisfy $T > R > P \geq S$ and $2R > T + S$. It is worth mentioning that although we choose a weak version, the results are robust and can be observed in the full parameterized space as well. For comparison, the considered snowdrift game has $T = 1 + r$, $R = r$, $S = 1 - r$ and $P = 0$, where $0 \leq r \leq 1$ represents the so-called cost-to-benefit ratio and payoffs satisfy $T > R > S > P$. The payoff matrices for both games are shown in the following formula

$$\begin{array}{cc} & \begin{array}{cc} C & D \end{array} \\ \begin{array}{c} C \\ D \end{array} & \begin{pmatrix} 1 & 0 \\ b & 0 \end{pmatrix} \end{array}, \qquad \begin{array}{cc} & \begin{array}{cc} C & D \end{array} \\ \begin{array}{c} C \\ D \end{array} & \begin{pmatrix} r & 1-r \\ 1+r & 0 \end{pmatrix} \end{array}. \tag{1}$$

Before the game, each player x is located on one site of networks and designated either as cooperator (C) or defector (D) with equal probability. With regard to the interaction networks, we consider two dimensional square lattice of size $N = L^2$ with periodic boundary conditions. Two types of players are initially considered and their spatial distribution is described as follows: player of type A whose faction is controlled by a parameter τ and player of type B whose faction is $1 - \tau$ and their factions keep constant during the whole simulation process. Player of type A (or B) has four (eight) interaction neighbors and four replacement neighbors. Obviously, when $\tau = 0$ (or 1), all the players x are type B (or A). However, when $0 < \tau < 1$, players will have different interaction neighbors, this kind of situation is more common in biological, social and economic systems. Therefore, this article mainly discusses how τ affects the evolution of cooperation, which, to large extent, corresponds to exploring the effect of the inequality of players. In addition, this type of setup of asymmetric neighborhoods (especially for interaction neighborhood) will lead to leader–follower-type relation, which is crucial for promoting cooperation, like hub nodes on scale-free networks [49].