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Friendship-based partner switching promotes cooperation in heterogeneous populations

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HIGHLIGHTS

- We develop friendship-based partner formation mechanism among tagged populations.
- We study how friendship (the weight of links) affects the evolution of cooperation.
- Strengthening the links connected prosocial partners favors cooperation.
- Moderate heterogeneity of tags can optimize cooperation.

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ABSTRACT

The forming of human social ties tends to be with similar individuals. This study concentrates on the emergence of cooperation among heterogeneous populations. A simple model is proposed by considering the impact of interplay between the evolution of strategies and that of social partnerships on cooperation dynamics. Whenever two individuals acquire the rewards by playing prisoner's dilemma game with each other, the friendship (friendship is quantified as the weight of a link) between the two individuals deepens. Individuals can switch off the social ties with the partners who are unfriendly and rewire to similar new ones. Under this partner switching mechanism, population structure is divided into several groups and cooperation can prevail. It is observed that the frequent tendency of partner switching can lead to the enhancement of cooperative behavior under the enormous temptation to defect. Moreover, the influence of discounting the relationship between different individuals is also investigated. Meanwhile, the cooperation prevails when the adjustment of friendships mainly depends on the incomes of selected individuals rather than that of their partners. Finally, it is found that too similar population fail to maximize the cooperation and there exists a moderate similarity that can optimize cooperation.

1. Introduction

Cooperation is extremely important in natural and human systems since it is an essential prerequisite for the emergence of every new level of organization [1]. Evolutionary game theory on networks provides a powerful framework for studying cooperation and has received much attention in the last decade [2–6]. Specially, the prisoner's dilemma game (PDG) [7]

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that describes the social dilemma [3] has attracted a lot of interest to study the evolution of cooperation among selfish individuals based on evolutionary game theory [2,8]. In PDG, a player can be either a cooperator or a defector. Both players receive a reward R for mutual cooperation and a punishment P for mutual defection. A defector can obtain the highest payoff T (temptation to defect) when he interacts with a cooperator, while the cooperator acquires the lowest payoff S (sucker's payoff). These four payoffs satisfy the following conditions: $T > R > P > S$ and $2R > T + S$. In a single encounter PDG, defection is the best action regardless of the opponent's choice. Thus defection prevails among egoists although mutual cooperation can create the optimum total reward. However, the contradiction emerges since natural selection can lead to cooperation. Therefore, a series of specific mechanisms including kin selection [9,10], direct reciprocity [11,12], indirect reciprocity [13,14], group selection [15–17] and spatial reciprocity [18,19] are proposed to understand the origin of cooperation.

In order to probe the evolution of cooperation, a more real-world scenario is taken into account by considering the coevolution between strategies and network topologies. Coevolution depicts a more realistic evolution of cooperation since not only the strategies but also the environment of the game evolves. Under the principles of coevolution, the strategies impact the topologies of the networks, and in return, the alterations of the networks eventually affect the outcomes of evolutionary cooperation. The interplay between strategy evolution and network evolution indeed fascinates abundant studies [20–46]. For instance, Fu et al. demonstrated that partner choice based on reputation significantly influences the enhancement of cooperation [29]. In their work, high-reputation individuals have the advantage of attracting new partners and maintaining their old partnership over low-reputation ones. Chen et al. presented a coevolutionary prisoner's dilemma model combined individuals' cooperative environment and tolerance threshold on adaptive networks and a moderate tolerance threshold is found to maximize cooperation [36]. Li et al. depicted an aspiration-based partner switching process, in which cooperation is promoted by an optimal aspiration level [43]. Cong et al. set up a coevolutionary model to probe the robustness of the time scales on the emergence of cooperation [44]. Wang et al. developed a model to survey coevolutionary cooperation on interdependent networks, in which the spontaneous optimal network interdependence for the alleviation of a social dilemma is shown [45].

The forming of human social relations and the emergence of cooperation are complex processes. Recently, it was found that friends' genotypes tend to be positively correlated [47]. The correlation in genotypes can be explained by specific systems (i.e., an olfactory gene set is homophilic) that may play an indispensable role in the formation or maintenance of friendship ties. Inspired by the existing studies, a simple model of coevolutionary prisoner's dilemma is presented in this paper concentrating on the interplay between evolutionary cooperation and friendship-based partner switching. Marked to be differentiated the nodes on the networks represent the individuals. Edges in the networks represent the pairwise partnerships and the weights of the edges denote the friendships between individuals. A marked individual plays a PDG with one of his neighbors and acquires an income, and then adjusts the friendship (the weight of the link) between these two individuals according to the payoffs that himself and his neighbor obtain from each other. The increasing of the links' weights is significantly impacted by the tags of individuals. Thereafter, the marked individual adjusts his social partners, breaks up the link with the lowest weight, and reconnects to a new individual who has an adjacent tag. It is realistic and reasonable in practice that individuals are more likely to shift their adverse partners and associate with similar new ones. We would like to study how cooperation evolve under the impact of this coevolution dynamics and show that such a coevolutionary mechanism will lead to the flourishing cooperation in the prisoner's dilemma. Furthermore, it is depicted that phenotypic similarity (similarity of tags) that acts as an indispensable role in partner switching will significantly affect the cooperation level.

In the framework of the evolutionary game theory, heterogeneity [48–65] provides an escape for cooperators from social dilemma. The effects of complex network topology, such as the heterogeneity of degrees [49,50], the clustering coefficient [48,51,58] and degree correlations [56,57], have important consequences for the evolution of cooperation. Moreover, heterogeneous reward and punishment [63], heterogeneity of investment [52,55,59,64,65] and the diversity of tags [62] also play a crucial role in the maintenance of cooperation. For instance, Santos et al. investigated the effects of heterogeneous populations that can promote the emergence of cooperation [49,50,52,55,61]. Perc et al. [54,60] studied the influence of heterogeneity on pairwise interactions and group interactions. Their surveys show that heterogeneous payoff distribution can lead to the opposite conclusions by pairwise interactions and group interactions. Chen et al. [63] found an optimal distribution of institutional reward and punishment for cooperation on scale-free network. In this study, we would like to present a tag-based partner switching process to investigate the evolution of cooperation. The formation of social relations does not only rely on individuals' strategies, but also rely on their diverse tags. Interestingly, the diversity of tags will significantly influence the coevolution of cooperation.

2. Model

Let us begin the evolution by constructing the population structure. In initial conditions, the network of social relations starts from an ER random network, in which the total $L = 5000$ links randomly pair the $N = 1000$ nodes (the average degree $z = 2L/N = 10$). Each node on the network represents an individual and has the equal probability to be a cooperator (C) or a defector (D). The individuals on the network are marked in order to be differentiated. The values of individuals' tags are in [0, 1]. The great difference value of two tags means that these two individuals are unfriendly and adverse. At the outset of the evolution, up to M different kinds of individuals are randomly distributed on the network and each individual has a