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Evolution of cooperation through adaptive interaction in a spatial prisoner's dilemma game

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HIGHLIGHTS

- A model to study the evolution of cooperation was established.
- The effect of adaptive interaction was discussed.
- An experiment designed to study the effect of the disconnecting mechanism was carried out.

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ABSTRACT

In this paper, we study the effect of adaptive interaction on the evolution of cooperation in a spatial prisoner's dilemma game. The connections of players are co-evolutionary with cooperation; whether adjacent players can play the prisoner's dilemma game is associated with the strategies they took in the preceding round. If a player defected in the preceding round, his neighbors will refuse to play the prisoner's dilemma game with him in accordance with a certain probability distribution. We use the disconnecting strength to represent this probability. We discuss the evolution of cooperation with different values of temptation to defect, sucker's payoff and disconnecting strength. The simulation results show that cooperation can be significantly enhanced through increasing the value of the disconnecting strength. In addition, the increase in disconnecting strength can improve the cooperators' ability to resist the increase in temptation and the decrease in reward. We study the parameter ranges for three different evolutionary results: cooperators extinction, defectors extinction, cooperator and defector co-existence. Meanwhile, we recruited volunteers and designed a human behavioral experiment to verify the theoretical simulation results. The punishment of disconnection has a positive effect on cooperation. A higher disconnecting strength will enhance cooperation more significantly. Our research findings reveal some significant insights into efficient mechanisms of the evolution of cooperation.

1. Introduction

Cooperation phenomena are extensive and profound in biological systems and human societies. However, explaining the mechanisms of the emergence and maintenance of cooperation remains a great challenge. Generally speaking, cooperators

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get less payoff than defectors, and cooperation is an evolutionary disadvantage. According to Darwin's theory, in the living struggle, behaviors that bring benefits to others rather than to the actor will eventually disappear [1]. However, this is inconsistent with the extensive cooperation phenomena in reality. The prisoner's dilemma game contributes greatly to refining why cooperation phenomena cause so much confusion and provides a powerful tool to study the evolution of cooperation. In the classical prisoner's dilemma game, there are two strategies for players to choose, unconditional cooperation C and unconditional defection D. We refer to the player as a cooperator if he chooses cooperation and as a defector if he chooses defection. Players achieve a certain payoff when playing the game with others. In a single round of the game, if two players both choose cooperation, each of them will get reward R; if the cooperator chooses cooperation while the defector chooses defection, the cooperator gets the temptation to defect T, and the defector gets the sucker's payoff S; if both choose defection, both get the punishment for defection P, satisfying $T > R > P > S$ and $2R > T + S$. Considering that T is larger than R and P is larger than S, defection is always the best strategy no matter what strategy the opponent has chosen. Defection is an evolutionarily stable strategy (ESS) [2] because it maximizes the player payoff in all different situations of the single round prisoner's dilemma game. In this way, players tend to defect rather than cooperate in order to get a higher payoff in the prisoner's dilemma game, but when all the players defect, the average payoff is lower than what they get through cooperating with each other, so the dilemma appears.

Scientists have published many studies examining the mechanisms of the emergence and maintenance of cooperation. Axelrod studied at a fundamental level why cooperation is not only natural but also the best survival strategy [3], and then, J. Maynard Smith proposed evolutionary game theory [2]. After the seminal idea of Axelrod [3], Nowak and May proposed a new cooperation mechanism named network reciprocity [4]. When players are placed in a spatial network, cooperators can gather together to reduce the losses against defectors through cooperating with each other, and cooperators can survive in clusters. Many approaches have been tested to further enhance the fraction of cooperators. Takuya Sekiguchi et al. introduced empty sites [5], and M. H. Vainstein et al. proposed diluted lattices to promote the evolution of cooperation [6]. Some studies have focused on mobile agents [7–11], in which they assumed that individuals are free to move to maximize their payoff; decreasing the individuals' mobility could promote the fixation of cooperators in the population [7]. Some studies have focused on heterogeneous activities [12–14] or ages [15–17], where players can select a source of strategy imitation from their neighbors in a biased way proportional to their ages [15]. Some studies have focused on mixed strategies [18–20]. For example, Christian Hilbe et al. considered three different strategy classes (partner strategies, competitive strategies and zero-determinant strategies) for the iterated prisoner's dilemma, and characterized these three classes within the space of memory-one strategies [18].

Some reports have proposed that the change in the interaction network is dictated by the urge to increase the focal player's payoff [21–25]. Several studies have investigated whether rewiring serves the increase in the payoff on a global scale [26–28]. Some works also introduced other properties of players as the influencing factors, such as attractiveness [29], compensation [24], and strategy [30]. Peng Lu investigated the heterogeneity of inferring reputation, which had not been adequately revealed before [31]. To describe the emergence of cooperation when suboptimal alternatives prevail, Wei Chen et al. proposed an evolutionary game model by considering the effects of aspirations [32]. Additionally, Christian Hilbe et al. explored the evolution of direct reciprocity in groups of n players [33]. From a more ambitious angle, Mark Abdollahian et al. studied the network emergence in an agent-based simulation of adaptive heterogeneous games and social systems [34]. Matja Perc and Attila Szolnoki gave a mini review of recent works on evolutionary games incorporating co-evolutionary rules, as well as giving a didactic description of potential pitfalls and misconceptions associated with the subject [35].

Furthermore, theoretical simulations are always performed in parallel with human behavioral experiments in evolution of cooperation research. Gary Charness et al. developed experiments and showed that higher cooperation is expected from others when mutual cooperation payoffs are higher [36]. Jillian J. Jordan et al. proposed theoretical models, performed experiments and revealed that third-party punishment serves to enhance the trustworthiness of punishers, even though it seems to be altruism [37]. Nishi, Akihiro et al. found that wealth visibility leads to greater inequality than wealth invisibility. Making wealth visible yields lower levels of overall cooperation [38]. Katrin Fehl et al. performed experiments and proved that frequent changes in a dynamic network can promote cooperation compared to those in a static network [39]. David G. Rand et al. provided empirical evidence proving that a system can maintain a high level of cooperation when individuals frequently update their network links, such as breaking network links with defectors and making new connections with cooperators [40].

Additionally, some co-evolutionary rules [41–43], which are strategy-neutral, have been investigated in the last few years. Szolnoki et al. [41] introduced a simple system in which players are allowed to make new collections if they have succeeded in passing strategy to their neighbors. They used this simple co-evolutionary rule to study evolution of cooperation in the prisoner's dilemma game. Subsequently, Szolnoki and Perc [42,43] exploited a co-evolutionary rule in two ways: First, deletions of existing links are happened whenever a player adopts a new strategy or its degree exceeds a threshold value; second, additions of new links are happened randomly after a given number of game iterations. For the fixed network structure in this paper, we can study the cooperation issue between players under dynamic links that can be connected or disconnected at various time points.

These studies provide us with insights into some simple yet general mechanisms behind the evolution of cooperation. Based on the above considerations, in this paper, we propose that the connections of players are co-evolutionary with cooperation. The change in connection between two players is mainly based on the strategies they took in the preceding round. If a player chose to defect, his neighbors will refuse to play the prisoner's dilemma game with him in accordance