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Comprehensive consideration of strategy updating promotes cooperation in the prisoner's dilemma game

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HIGHLIGHTS

- A new method of strategy updating is applied in the prisoner's dilemma game.
- Stochastic player applies the classical Fermi rule for strategy updating.
- Smart player considers its neighbors' payoff and environment for strategy updating.
- Results illustrate that the increase of smart players promotes cooperation.

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ABSTRACT

We investigate how the cooperation emerges in the square lattice when individuals play the prisoner's dilemma game by adopting different strategy updating methods. First, we classify individuals in two classes at the strategy updating stage: stochastic players and smart players. The stochastic players are those who take the classical Fermi rule, while the smart players are those who make comprehensive evaluation for strategy updating. Second, we adopt Dempster–Shafer theory to combine smart players' evaluations from payoff and environment aspects. Simulation results reveal that the comprehensive strategy updating method has a positive impact on the emergence of cooperation. Furthermore, the number of cooperators increases with the proportion of smart player increase. However, it is noteworthy that defector never become extinct, even all players in the network are smart ones. This is because some smart players would maximize their payoff if they choose to betray their cooperative neighbors. Our work in this paper may provide further understanding of the origin of cooperation in social and biology systems.

1. Introduction

It is well known that cooperation exists widely in many biological, social and economic systems [1], and plays an important role for the functionality of these systems. How cooperation sustains among selfish individuals is still an open issue. So far, evolutionary game theory [2–11] has been applied effectively to investigate this problem. Many meaningful game models are proposed, including the prisoner's dilemma game (PD) game, the snowdrift game (SG) and the public goods game (PGG). In the classical prisoner's dilemma (PD) game, each pair of players has to make a decision simultaneously whether one individual wishes to cooperate with the other or not. The game offers a defecting player the highest income when

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facing a cooperator. On the other hand, the cumulative income of two cooperators is higher than that of a cooperator–defector pair and obviously higher than two defectors [12]. Based on each player's own interests, cooperators cannot outperform defectors, especially when players who would like to defect are faced with a relatively higher value of temptation to defect. Then cooperation is doomed to become extinct. Therefore, investigating the emergence and maintenance of cooperative behavior among selfish individuals is of vital importance. Previous researches have proved that specific topology of players defining the interactions among them, mechanisms such as kin selection, reciprocity, strategy complexity [13] and time scale of strategy updating [14] play a key role in the emergence of cooperation.

Since the pioneering work of Nowak and May [15], evolutionary games have been widely studied on lattices [16,17] and complex networks [18–23]. Recently, the evolutionary game with limited interactions among two kinds of individuals on a square lattice is studied [24]. It is found that cooperation is boosted when individuals' strategy selection time evolves based on their historical learning information in Ref. [25]. Moreover, researchers found that a phase transition characterized by the emergence of a large spanning cooperator cluster occurs when the initial fraction of the cooperators exceeds a certain threshold [26]. Evolutionary games on scale-free networks with tunable degree distribution is studied [27]. Too strong heterogeneity might go against the maintaining of cooperation. Chen and Wang [28] have studied the evolutionary PD game on small-world networks for different average aspiration levels under the stochastic updating rule, and found that there exists an appropriate intermediate aspiration level leading to the maximum value of cooperation. Furthermore, Ref. [29] reveals that lower mobility can lead to a higher level of cooperation when compared with that of higher mobility. Cautiousness index [3] is assigned to individuals to control its learning activity. The work shows that cooperation can be greatly promoted in the spatial prisoner's dilemma game. Ref. [30] develop a framework to investigate the role played by diversity in promoting cooperation in evolutionary game theory. It is found that cooperation would not benefit if diversity is too strong. The similar result, i.e., a suitable degree of diversity among individuals can promote the emergence of cooperation, is also found in Ref. [31].

In spite of the achievements of the recent years, the environment of player and its neighbors has received relatively little attention till now. Although this kind of mechanism is almost ubiquitous in a individual's decision-making process, only a few studies have addressed the effects of environment on evolutionary dynamics [32–39]. Therefore, it is of future interest to inspect the dynamics of PD game with the consideration of environment. As a matter of fact, the strategy updating is a decision-making process. Every player has to decide whether to keep its own strategy or to imitate its neighbor's strategy. In most studies, the classical Fermi rule is utilized to compute the probability if a player X would imitate its neighbor Y. Only the payoff of X and Y is considered in this rule. In real world scenarios, there always exist some smart players unwilling to make decision in such a simple way. They would take both payoffs and the environment of their neighbors and the global environment into consideration before making the strategy updating decision. In this paper, we investigate the impact of environment in PD game when different players adopt different strategy updating methods. Specifically, some players simply apply the Fermi rules to update their strategies; the others (namely, smart players) take both the environment and the payoff into account in the strategy updating stage. Smart players would evaluate their neighbors from two perspectives—payoffs and environment, respectively. Then, we adopt Dempster–Shafer theory to make a comprehensive evaluation of strategy updating. The simulation results show that the fraction of cooperation becomes larger when increasing the number of smart players in the network. Besides, we have also studied some typical initial configurations which may influence the emergence of cooperation [40,41], and found the same effect of smart players. It means that the comprehensive consideration of smart players has a positive impact on the emergence of cooperation. The results may provide further understanding of the origin of cooperation in social and biology systems.

The rest of the paper is organized as follows. The proposed model is described in Section 2. Next, Section 3 presents the numerical simulations and analysis. Finally, in Section 4 we conclude with a summary.

2. Model

The spatial PD game is staged on a square lattice of size $L \times L$ with periodic boundary conditions. In terms of the weak PD proposed in Ref. [42], the payoffs are given as follows: $T(1 < T = b < 2)$ denotes the temptation to defect. $R(R = 1)$ is the reward for mutual cooperation, and P and $S(P = S = 0)$ are the punishment for mutual defection and sucker's payoff, respectively. Although this formulation of the weak PD game has $P = S$ rather than $P > S$, it captures simply the essential social dilemma, and accordingly, the presented results can be considered fully relevant and without loss of generality with respect to more elaborated formulations of the payoffs.

Initially, each player x is designated as a cooperator or defector with equal probability. At every time step, a player in a network plays the PD games with all its neighbors and obtains accumulated payoff U through all games with its neighbors. The next is to update strategy. Players are classified in two classes at this stage: stochastic players and smart players. The stochastic players are those who select one of their own neighbors randomly and then decide whether to imitate its strategy or not. The smart players are those who consider the comprehensive evaluation of their neighbors' payoffs and environments. Let v denotes the fraction of smart players in the network.

A stochastic player x revises its strategy according to the following Fermi rule [17]. It randomly selects one of its neighbors y. Let U_x and U_y denote the accumulated payoffs of player x and player y obtained from the last iteration, respectively. Player