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Strategy-updating depending on local environment enhances cooperation in prisoner's dilemma game

Yifan Zhang [a,b], Gang Shu [c], Ya Li [a,*]

[a] School of Computer and Information Science, Southwest University, Chongqing 400715, China
[b] School of Hanhong, Southwest University, Chongqing 400715, China
[c] School of Physical Science and Technology, Southwest University, Chongqing 400715, China

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ABSTRACT

An evolutionary prisoner's dilemma game is studied on a square lattice when local environment is considered. And a new strategy updating rule is utilized in this game. First, individuals are classified as two classes: stochastic players and intelligent players. The stochastic players are the ones who adopt the rule of replicator dynamics to update strategies, and the intelligent players are those who make a decision through comprehensive considerations of the local environment (namely, the information of different-strategy neighbors' environment). Second, the intelligent player's evaluation is calculated from payoffs and local environment by Dempster–Shafer theory. The results indicate that the new strategy-updating method promotes cooperation when intelligent individuals utilize the information of different-strategy neighborhoods. Moreover, the increasing number of intelligent player promotes cooperation level. Furthermore, it is noteworthy that cooperators will finally coexist with defectors no matter what the proportion of intelligence is, which is worthy to think about.

1. Introduction

Based on survival of the fittest in nature selection of Darwinian theory, individual selfishness may drive individuals to harvest more gains during the competition and evolution [1]. For example, the strategy of defection is normally optimal choice for individual in classical prisoner's dilemma game (shortly, PD) [2–5]. However, the cooperative behaviors are widespread in real world. And the congregate cooperation has an ability to urge the population to reap the greatest benefit [6]. With the wide existence of cooperation in many social, biological, political and economic systems, game theory plays a significant role and provides a functional framework to understand and analyze the function of cooperative behaviors [7]. Thus, the potential methods about promoting cooperation have become a challenging issue, which attracts lots of attention and interest [8,9]. Many meaningful and important game models have been utilized to analyze competition among individuals, such as the snowdrift game [10,11], the ultimatum game [12–14], the public goods game [15,16], etc. Scientists from various areas indicate the importance of evolutionary game theory in studying cooperation, and it has been widely applied in many fields [17]. For instance, the diffusion process of rumor is investigated in the evolutionary game framework [18], and different social dilemma perceptions in evolutionary multi-games are analyzed [19]. What is more, in Ref. [20], co-evolution of cooperation between network and strategy is stressed.

* Corresponding author.
E-mail address: liyaswu@163.com (Y. Li).

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So far, previous researches have proved special topology of individuals affects the interactions, and quite a few mechanisms such as kin selection [21–23], direct selection [24], indirect selection [25], group selection [26,27], spatial and network selection [28–30] and payoff matrix [31,32] have played an extraordinarily important role in cooperation. In particular, since Nowak and May presented a surprising pioneering work of spatial game model, which promotes cooperation among selfish individuals [33], evolutionary game has been widely explored on complex networks [34–36], lattices [37,38] and so on. Spatial reciprocity provided a powerful model to investigate further cooperation, and many related works were triggered, including reputation [39], topological setups [40], reciprocity [41], environment information [42], migration [43] and so on [44].

Previous investigations suggested that the cooperators can form some tight clusters to resist the invasion of defectors in networks when the updating-strategy is adopted according to imitation dynamics [45,46]. Wu et al. presented that updating-strategy guided by some aspiration-driven rule can promotes cooperation in a square lattice [47]. In addition, some typical initial configurations in evolutionary prisoner's dilemma game were introduced. For example, different kinds of individuals and aspirations can promote cooperation in the evolution system, and extortion strategies are also important in evolution of cooperation [48–50]. Li et al. also explored how updating-strategy method affects the cooperation in lattice network, and proposed that comprehensive analysis of strategy updating with payoff and global environment information in evolutionary prisoner's dilemma game can promote cooperation level [51]. Huang et al. researched the effect of sub-population in evacuation crowd and some social dilemmas, which found that rational sub-population or small group is a useful way to improve cooperation level and solve many dilemmas [52,53]. Yu et al. explored system crash in complex networks, and their results showed that those accessible local information of individual may lead to the "peculiar" dynamics of system crash [54]. These motivate us to investigate further about how the evolutionary prisoner's dilemma game plays in a lattice framework based on different-strategy neighbors' local environment information.

As is known to all, people get used to make their decisions by learning and imitating their friends or neighbors, which improves the level of their decisions sometimes. Some players make decisions through a comprehensive consideration from the perspectives of payoffs and global environment in [51], but in fact, individuals normally make a decision by considering their different-strategy neighbors rather than all neighbors. So in order to describe and simulate this situation, we proposed a new model where individuals update their strategies through a comprehensive consideration from the two perspectives.

In the model, some players (namely, stochastic players) update their strategy by the rule of replicator dynamics; others (namely, intelligent players) make a comprehensive consideration from the perspectives of payoffs and local environment, which means intelligent players would make comprehensive evaluations of their different-strategy neighbors from two dimensions. The results indicate that the new mechanism of strategy-updating could promote the fraction of cooperation with increasing number of intelligent individual. In addition, we also studied the emergence of cooperation through the spatial distribution of individual clusters, finding some interesting results, which is worthy to consider.

The remainder of the paper is organized as follows. Firstly, the proposed model and method are described detailed in Section 2. Then, Section 3 illustrates the numerical simulation results and analyses. Finally, summaries are drawn in Section 4.

2. Model

The evolutionary Prisoner's dilemma game is simulated in a $L \times L$ square lattice with periodic boundary conditions. According to the weak PD game, payoffs are defined as follows: T $(1 < T < 2)$ is the temptation to defect, and b $(b = T)$ denotes the temptation strength. R $(R = 1)$ denotes the reward for mutual cooperation. P and S $(P = S = 0)$ represent the punishment for mutual defection and the sucker's payoff, respectively. Although the classical PD game is $P > D$ rather than $P = D$, the simulation results are accordant. For simplicity and relevance, without loss of generality, the model only consider the weak PD games.

At the beginning, each individual has equal probability to be randomly set as a cooperator or a defector. Each time round, an individual plays the PD game with all its neighborhoods in a network, obtaining accumulated payoff U. The next is updating strategy stage, in which individuals are classified in two classes: stochastic players and intelligent players. The stochastic players are the people who select a neighbor randomly and decide whether to imitate the neighbor's strategy or not. And the intelligent players are different but more smart, who would not only consider the payoff of its neighbors, but also the local environment information of its neighbors.

First of all, for characterizing the randomness of stochastic players, the stochastic individuals randomly select one of its neighbors to calculate the imitation probability. It simulate that the stochastic players make decisions without investigation. A stochastic player imitates a random-selected neighbor's strategy just from the perspective of payoff with the probability:

$$W_1(i \to j) = \frac{P_j - P_i}{4T} \tag{1}$$

Where P_i and P_j denote the payoff of i and j, respectively. T is the temptation to defect. The probability indicates that i is more inclined to imitate j's strategy when the payoff of j is much higher than i.

At the same time, intelligent individuals would make a decision through comprehensive analyses of all information. On the one hand, intelligent individuals consider the payoff information of different-strategy neighbors. On the other hand, the local environment information of different-strategy neighbors are also considered. In the proposed model, the global