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Inferring the reputation enhances the cooperation in the public goods game on interdependent lattices

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A B S T R A C T

In this paper, we mainly probe into the evolution of cooperation in the spatial public goods game on interdependent lattices by introducing the reputation inferring mechanism into the strategy selection. During the strategy update, the individual reputation is commonly determined by two corresponding partners on interdependent lattices, where the imitated neighbors are chosen in accordance with the average, maximum and minimum of reputation values between two partners within the neighborhood of a focal player. A large plethora of simulations indicate that three reputation computing rules all lead to the promotion of cooperation when compared to the traditional public goods game model. Among them, the promotion of cooperation under the average and minimum schemes are relatively better than that produced by the maximum rule. The detailed cluster formation and reputation distribution are provided to illustrate the slight difference between the outcomes under these three decision making criterions, in which the choice of learning objects is governed by their reputations. Thus, we can conclude that current results are further conducive to understanding the universal and persuasive cooperation within many natural, biological, social and even man-made systems.

1. Introduction

Although the collective cooperation is a wide spread phenomenon in the nature and human society [1], the cooperation is usually not an optimal strategy from the perspective of the theory of game, that is, cooperation is not a Nash equilibrium point under numerous circumstances [2] and even the so-called tragedy of commons appears [3]. Thus, how to interpret this inconsistency of cooperation between the theory and practice has become an active topic within the academia [4,5], and aroused extensive interests in biology, physics, economics and social science, and engineering sciences etc. Among them, the evolutionary game theory has provided a powerful framework to illustrate the evolution of cooperation [6]. Over the past decades, several typical protocols [7] for enhancing the collective cooperation, such as kin selection [8], direct or indirect reciprocity [9–11], group selection [12] and spatial reciprocity [13], have been found to strongly favor the persistence and emergence of altruistic behavior.

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It is particularly worth mentioning that the spatial reciprocity [13] has endowed the cooperators to defend the invasion of defectors by organizing the clusters on regular lattices, and to further broaden the survival chance of cooperators in the dilemmatic conditions. After this seminal work, other related methods [14,15] are also added into the spatial structure to further illustrate the evolution of cooperation. Yet, the regular lattice is far from characterizing the topology of real-world systems [16–20] since they are often heterogeneous and exhibit the small-world [21] or scale-free [22] properties. Thus, it is of utmost importance to explore the evolutionary cooperation behavior in complex networks (for the recent reviews, we recommend the readers to refer to [23–26]). Santos and Pacheco [27] found that the cooperation is tremendously elevated in scale-free networks since the cooperative clusters are created once the hub nodes are occupied by the cooperators, and then this kind of phenomenon of immense enhancement has been observed in prisoner's dilemma game [28,29] and public goods game (PGG) [30,31]. Furthermore, many practical networks are often interacting, interconnected or interdependent [32–34], for instance, communication networks and power grids can only function through their mutual support, in which power systems provide the electrical energy to the communication networks and also depend on the communication systems to transmit the control signal, vice versa. Hence, evolutionary cooperation on interdependent systems has become an active and challenging issue [35], and especially great progresses regarding the emergency of cooperation on interdependent networks [36–43] have been made in the very recent years.

Meanwhile, exploring the direct and effective method to promote the cooperation is still significant in the practice. As an example, rewarding [44,45], utility weighting [46,47] and individual mobility [48,49] for the risk aversion, are also identified as viable means to foster the cooperative behaviors. Furthermore, under the realistic circumstances, the reputation often influences the individual life and career development. In the business, a reputable individual can easily perform various transactions; in the bank, a well-credited person can obtain the higher lines of credit; in the academic community, a prestigious researcher may easily apply for the funding grant or persuade the reviewers to make potentially positive comments on their proposals or manuscripts. Therefore, the role of reputation mechanism in the evolution of cooperation has also attracted a lot of concern recently. Several typical examples include: Through alternating between the public goods and indirect reciprocity games during the experiments, Milinski et al. [50] indicated that the public cooperation behavior can be elevated into an unexpectedly high level; Fu et al. [51] found that the cooperation strategy can be adopted by most of players if each player can be allowed to have an opportunity to change his strategy and switch the game interaction partner, in which the selection of interaction partner is determined by the image score or reputation of his game peers; Wang et al. [52] proposed a new reputation inferring mechanism in the social dilemma to denote the influence of the cost and error of information dissemination on the collective cooperation, and validated that reputation inferring could thus be enormously beneficial to the emergence of cooperation; As a further step, Chen et al. [53] presented a novel adaptive reputation assortment scheme, which automatically categorize all players into two classes of ones with different strategy spreading abilities, under the spatial PGG model and the results demonstrated that the cooperation can be drastically promoted when compared to the standard PGG behavior in the spatial lattice.

However, to the best of our knowledge, the reputation mechanism cannot be considered in the interacting and interdependent systems. Thus, in this paper, we try to fill this gap, and introduce the reputation property into the interdependent lattices to further investigate the spread of cooperation within complex real-world systems. The remainder of this paper is organized as follows. At first, in Section 2, we present our PGG model considering reputation in detail. Then, large quantities of simulations are carried out in Section 3 to validate the cooperative behaviors of proposed PGG model. At last, we end this paper with some concluding remarks in Section 4.

2. The reputation-based PGG model on interdependent networks

The public goods game is placed on two separated square lattices with von-Neumann neighborhood, each of size $L \times L$, in which the interdependency is built through the reputation inferring of corresponding players during the strategy learning. Initially, each player (say x) is designated as a cooperator ($s_x = C$ or 1) or defector ($s_x = D$ or 0) with the 50% probability. Meanwhile, each player will be endowed with a random reputation value-an integer taking from the interval [1, 100] to denote the value of individual reputation, and this value will be increased (decreased) by one if he decides to cooperate (defect) at each time step during the evolution of cooperation. In addition, before iterating the game round, each player is assigned with a given probability $0 \leq p \leq 1$ so as to characterize his reputation inferring ability since the player can only possess limited and different inferring ability to evaluate their opponents due to the cost and error of information dissemination. This setting is performed uniformly irrespective of his initial strategy and remains unchanged during the simulations.

Then, the accumulation of payoffs P_x for each player on two networks will follow the same standard procedure according to the PGG rule. That is, each agent will participate in $G = k + 1$ PGG groups, in which one group centers around himself (i.e., focal player) and other k groups focus on his k nearest neighbors ($k = 4$ for von-Neumann neighborhood). Within each group, all players will decide at the same time whether to invest a fixed share into the public resource pool, without loss of generality, the player will contribute one unit if he adopts the cooperation strategy ($s_x = 1$), or else not contribute anything ($s_x = 0$). Thus, the number of cooperators will be counted to characterize the total contribution inside a PGG group. Afterwards, the total contribution will be multiplied by a synergy factor (r) greater than 1.0, and then be distributed evenly over all players within this PGG group. Accordingly, the accumulated payoff that will be obtained by a player x can be