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Understanding cooperative behavior of agents with heterogeneous perceptions in dynamic networks

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HIGHLIGHTS

- Effect of heterogeneous perceptions on cooperative behavior is studied on dynamically varying network.
- For small temptation a large value of network evolution strength warrants an optimal resolution of social dilemma.
- For large temptation an intermediate value of network evolution strength is the most beneficial for the evolution of cooperation.

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ABSTRACT

In reality, social diversity is omnipresent. Motivated by the fact that different agents may get different perceptions for the same social dilemma, we extended the concept of heterogeneous perceptions to dynamically varying network and investigate the impact on the evolution of cooperation in this paper. Here, the heterogeneous perceptions of different agents are modeling by spatial multigames, which are characterized by two different social dilemmas: the traditional prisoners' dilemma and the snowdrift game. The dynamic network, on the other hands, is a network whose link weights are coevolved with game strategy. By conducting large-scale Monte Carlo simulations, we draw a conclusion that for small temptation a large value of network evolution strength warrants an optimal resolution of social dilemma; while for large temptation an intermediate value of network evolution strength is the most beneficial for the evolution of cooperation. In addition, numerical simulations also indicate that the higher the value of the proportion of the snowdrift game is, the more widespread cooperative behavior becomes except for some small fluctuations. Taken together, our results support that the agents with heterogeneous perceptions in dynamic network are strong facilitators of cooperation promotion, which will provide a new insight for the further research.

1. Introduction

In multi-agent system, there exist a large number of selfish agents interacting with each other. Here, the interaction among agents are often characterized by the complex network [1–7]. Since the resource is limited, the purpose of each agent often conflicts with the global aim of the system, here the global aim of the system is measured by the total payoff. Thus, the problem called social dilemma occurs. According to the Darwin's theory, most of the agents will select defection in the end. However, cooperation is ubiquitously observed in the networked system, real world and different organizations

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ranging from microorganisms and animal groups to human societies. In fact, social dilemma often arises in many situations in multi-agent systems, such as file sharing in P2P systems, wireless sensor networks and so on [8,9].

To resolve this dilemma, researchers from multiple disciplines such as biology, physics, mathematics and engineering have proposed many mechanisms and methods [10–14]. Among these methods, the evolutionary game theory framework is the most popular one [13,15–17]. Here, evolutionary game theory is the theory mainly about dynamic adaptation and learning of repeated games, which is played by bounded rational agents. Repeated prisoner's dilemma and snowdrift game served as two paradigms for expressing the social dilemma in the evolutionary game theory [18–20]. In the repeated prisoner's dilemma game, there exist two competing behaviors: cooperation and defection. Traditionally, since the defection agents get the highest fitness, the prisoner's dilemma game will completely fall into the pure defection phase when the network model is a fully connected network. Apparently, the fully connected network is an ideal model, which is not suitable for the complex structure of agents in multi-agent system. The pioneering work of Nowak and May [21] shown that the spatial structure enables the cooperative agents to form clusters to prevent the exploitation of defection agents. Along with the spatial evolutionary game framework, the interaction structure of agents can be modeled by other kinds of networks. Santos et al. [22] have discovered that scale-free networks can promote the emergence of cooperation in both repeated prisoners' dilemma game and snowdrift game. After that, the effect of network model has been intensively studied as a paradigm for illustrating how cooperative behavior evolves, which includes the small-world network [23], hierarchy network [24,25] and interdependent networks [26–28], and these models have been proved valuable for solving the social dilemma to some extent. Besides, other mechanisms promoting cooperation have been introduced, such as reputation [29–31], punishment and reward [32–34], mobility of agents [35,36], social diversity [37–40] and heterogeneous strategy updating attitudes [41], to name but a few.

Generally, the network models of the above mentioned works are static networks. However, in the real situation, the interactions between agents are changing with time. Therefore, understanding the cooperative behavior in dynamic network is practically meaningful, which has attracted many attentions within the framework of evolutionary game theory [42–47], and further references can be found in [48]. Recently, Huang [49] proposed the mechanism of coevolution of game strategy and network weight to study the effect of network dynamic on the cooperative behavior, and found that the intermediate value of network evolution dynamic is the optimal resolution of prisoners dilemma. More recently, Chu [50] studied the effect of heterogeneous time scale of network evolution dynamic on the cooperative behavior. On the other hand, agents in the multi-agent system may have heterogeneous perceptions for the same situation. In detail, when encounter with the same social dilemma, different agents may perceived differently.

Motivated by these two assumptions, we study the cooperative behavior of agents with heterogeneous perceptions in dynamic network in this paper. In detail, we assume that agents with heterogeneous perceptions use different values in the payoff matrix, thus there exist two types of game model in the multi-agent system, which including prisoners' dilemma and snowdrift game. In addition, we assume the network dynamics is based on the coevolution mechanism of our previous work [49]. To the best of our knowledge, few papers discuss the effect of heterogeneous perceptions of agents on dynamic network, therefore, it is meaningful for solving the puzzle of social dilemma.

The rest paper is organized as follows. Section 2 introduces the evolutionary multigames dynamics including the heterogeneous perceptions model, the network evolution model as well as the cooperative behavior dynamics on the dynamic network. Section 3 explores the emergence of cooperation as well as network dynamics in the multi-agent system by large-scale Monte Carlo simulations. The concluding remarks are given in Section 4.

2. Evolutionary multigames

As a well-known saying that comes from Shakespeare: "There are a thousand Hamlets in a thousand people's eyes". It means that different people may have different views when facing the same situation. Indeed, it is often the case that different agents perceive differently for a particular social dilemma. Therefore, the most intriguing question is how the heterogeneous perceptions of agents play a role in the cooperation level in the whole population. Mathematically, we adopt different payoff matrices to describe the heterogeneous perceptions of agents. In detail, each instance of the game involves a pairwise interaction, here the mutual cooperation obtains the reward R, the mutual defection yields the punishment P, and the mixed choice gives the cooperator the sucker's payoff S and the defector the temptation T. Inspired by the previous work concerning the multigames [51,52], we use different value of S to characterize the heterogeneous perceptions. In detail, in the traditional prisoner's dilemma, which adopts $T = b, R = 1, S = -\beta$ and $P = 0$, and the payoff ranking of traditional prisoner's dilemma game is $T > R > P > S$. While in the snowdrift game, which adopts $T = b$, $R = 1$, $S = \beta$ and $P = 0$, and the payoff ranking of traditional snowdrift game is $T > R > S > P$. Apparently, this slight variation induces a major change in the game dynamics with the creation of a second Nash equilibrium where both strategies coexist.

We study the evolutionary multigames with agents located on the regular square lattice with Moore neighborhood and periodic boundary conditions. Here, the number of the agents is equal to $N = L^2$. On the contrary to the previous work [51], we consider the regular square lattice as a dynamic network, whose link weights are coevolved with game strategy. Here, the link weight is introduced into evolutionary game via the adjacency matrix of network $W = \left(w_{xy}\right)_{N\times N}$. Initially each agent is designed either as a cooperator C or defector D with identical probability, and the weight between agent x and agent y has the equal value $w_{xy} = 1$. For the multigames, we assume that a fraction ρ of agents chosen at random use the snowdrift