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Promote of cooperation in networked multiagent system based on fitness control

Wenfeng Deng[a], Keke Huang[a,*], Chunhua Yang[a], Hongqiu Zhu[a], Zhaofei Yu[b,*]

[a] School of Information Science and Engineering, Central South University, Changsha 410083, China
[b] School of Electronics Engineering and Computer Science, Peking University, Beijing 100871, China

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ABSTRACT

How did cooperative strategy evolve remains an open question across disciplines. In most previous studies, they mainly consider the analyzing of game dynamics on the networked multiagent system under different mechanisms. However, there often exists a “government” who regulates the strategies of agents centralized or decentralized in reality. Motivated by this fact, we introduce a fitness control method in this paper, and investigate the strength of external fitness control on the game dynamics in networked multiagent system. According to the classic Monte Carlo simulation, we found that the fitness control rule can significantly enhance the cooperation level in networked multiagent system. In particular, we found that the stronger the local fitness control is, the more widespread cooperative strategy becomes. More interestingly, we found that although the local fitness control is less information needed, it is more powerful in cooperation promotion than that of global fitness control rule. Thus, it is practically significant and will provide a new insight into the control of game dynamics in networked multiagent system for the further research.

1. Introduction

In social and biological systems, there exist a large number of selfish agents, and the agents often interact with each other [1–4]. Here, the interactions between different agents are often modeled by network model, and the system is often named as the networked multiagent system [5–7]. In the networked multiagent system, the purpose of each agent often conflicts with the total purpose of the system, and the problem named social dilemma occurs. To resolve this puzzle, the framework of evolutionary game theory was proposed, which has been used as a powerful mathematical model to analyze the social dilemma [8–10]. The prisoner’s dilemma which was the most famous social dilemma model has been intensively investigated [11–13]. In the prisoner’s dilemma, there exist two discrete strategies for agents to choose: cooperation and defection. Here, cooperation is the Pareto efficiency strategy, but defection is the equilibrium strategy, which means that most of the agents will select the defection strategy in the end. Except for the network model and game model, the decision-making protocol also has a tremendous influence on the game dynamics [14–16]. In summary, the game dynamics in the networked multiagent system consists of three fundamental factors: the network model, the game model and the decision-making protocol.

* Corresponding authors.
E-mail addresses: huangkekefendou@126.com (K. Huang), yzf714@126.com (Z. Yu).

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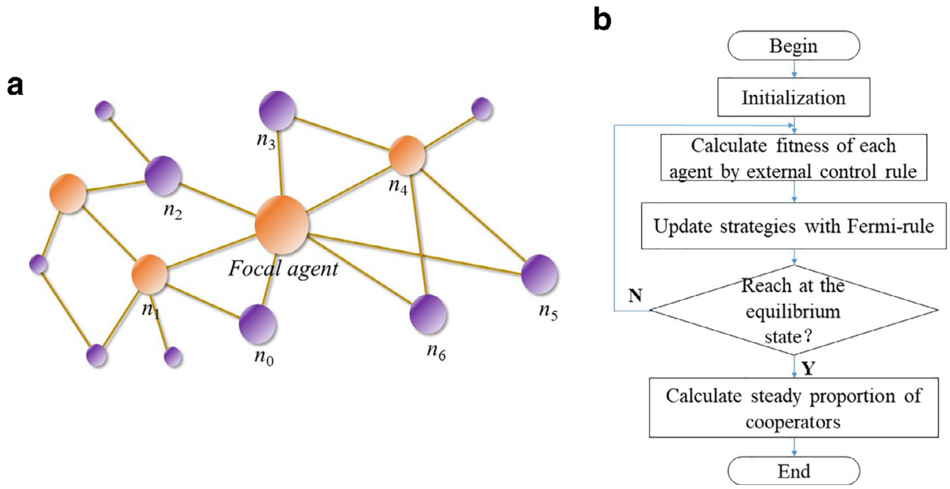

Fig. 1. Illustration of game dynamics in the networked multiagent systems. (a) The schematic diagram of networked multiagent systems, (b) The algorithm of the proposed fitness control method.

In recent decades, there are lots of works related to the three fundamental factors have been proposed to investigate the game dynamics in the networked multiagent system, including some theory based studies and experiment based studies [17–19]. For the network reciprocity, the pioneering work was proposed by Nowak and May in 1992, which shows that the regular lattice can induce the emergence of cooperation by network reciprocity, and they found that the cooperators can resist the invasion of defectors by forming into clusters [20]. Along with this direction, other types of network have been studied, such as small-world networks [21], scale-free networks [22–24], hierarchy networks [25] and interdependent networks[26–28]. For the game model, the pairwise snowdrift game model, prisoner's dilemma, and group-based public goods game are served as paradigms for expressing a social dilemma within the framework of evolutionary game theory [8,29,30]. Typically, as the equilibrium state of prisoner's dilemma is pure defection, the dilemma strength of prisoner's dilemma is the biggest one among different game models. Therefore, we use it as the game model for our work. For the mechanisms related to decision-making protocol, the Fermi rule [31,32], proportion based rule [33,34] as well as adaptive learning rule including Q-learning rule [35] and enforcement learning rule [36] were proposed. Other comprehensive cooperation promotion mechanisms, such as heterogeneity [29,37,38], reputation [39–41], punishment and reward [42,43] and mobility of agents [44,45] have been studied, and these methods have been proved valuable for solving the social dilemma to some extent.

Generally, previous works mainly consider the analyzing of game dynamics in the networked multiagent system under different mechanisms. However, there often exists a "government" who often regulates the strategies of agents centralized or decentralized in reality. The government often tries to control the strategies as well as fitness by imposing an external regulation to the agents who belong to his scope. Motivated by the strength of a centralized or decentralized external regulation, we introduce a fitness control rule to guide the game dynamics of networked multiagent system. To the best of our knowledge, few papers discuss the fitness control rule on the game dynamics, therefore, it is novel and meaningful for solving the puzzle of social dilemma.

The rest of this paper is organized as follows. Section 2 introduces the mathematical model of the evolutionary game dynamics in networked multiagent system. Section 3 explores the emergence of cooperation by fitness control according to the numerical simulation results. The concluding remarks are given in Section 4.

2. Mathematical model

Generally, game dynamics in the networked multiagent system consists of three fundamental factors: (1) the network model, (2) the game model and (3) the decision-making protocol. As shown in Fig. 1 (a), agents in the multiagent system hold with given strategies, and then acquire payoffs by interacting with their directed neighbors. After that, agents will adjust their strategies based on their fitness. Here, the fitness of a given agent is regulated by a global or local fitness control rule was investigated in this paper, and the algorithm of the proposed fitness control method shown in Fig. 1 (b). In detail, the global fitness control rule depends on the payoffs of the whole system, the local fitness control rule, on the contrary, only depends on the payoffs of his directed neighbors. The alternative iterations of the above processes lead to the evolution of cooperation in the networked multiagent system.

Here, we firstly introduce the interaction model between agents: the prisoner's dilemma model. The payoff matrix is defined as follows:

$$P_{PD} = \begin{bmatrix} R & S \\ T & P \end{bmatrix} \tag{1}$$