Physica A xx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa

Q1 Cooperation in memory-based prisoner's dilemma game on interdependent networks

Q2 Luo Chao [a,b,*], Zhang Xiaolin [a,b], Liu Hong [a,b], Shao Rui [c]

[a] School of Information Science and Engineering, Shandong Normal University, Jinan 250014, China
[b] Shandong Provincial Key Laboratory for Novel Distributed Computer Software Technology, Jinan 250014, China
[c] The center of network optimization, Shandong Mobile Communication, Jinan 250024, China

HIGHLIGHTS

- The evolution of cooperation for memory-based players is based on interdependent lattices.
- Investigate the mutual influence of memory effect and interdependence.
- Find the optimal region of memory length and interdependence level for cooperation.
- Find the distinct roles of different kinds of players in the evolutionary game.

ARTICLE INFO

Article history:
Received 16 September 2015
Received in revised form 5 January 2016
Available online xxxx

Keywords:
Evolutionary game
Prisoner's dilemma game
Interdependent networks
Memory effect

ABSTRACT

Memory or so-called experience normally plays the important role to guide the human behaviors in real world, that is essential for rational decisions made by individuals. Hence, when the evolutionary behaviors of players with bounded rationality are investigated, it is reasonable to make an assumption that players in system are with limited memory. Besides, in order to unravel the intricate variability of complex systems in real world and make a highly integrative understanding of their dynamics, in recent years, interdependent networks as a comprehensive network structure have obtained more attention in this community. In this article, the evolution of cooperation in memory-based prisoner's dilemma game (PDG) on interdependent networks composed by two coupled square lattices is studied. Herein, all or part of players are endowed with finite memory ability, and we focus on the mutual influence of memory effect and interdependent network reciprocity on cooperation of spatial PDG. We show that the density of cooperation can be significantly promoted within an optimal region of memory length and interdependent strength. Furthermore, distinguished by whether having memory ability/external links or not, each kind of players on networks would have distinct evolutionary behaviors. Our work could be helpful to understand the emergence and maintenance of cooperation under the evolution of memory-based players on interdependent networks.

1. Introduction

In the context of Darwinian theory of evolution, altruistic behaviors in social group seem incomprehensible. However, Q3 altruism or cooperation, even if costly to the individuals, can be widely found in a realistic world, that coexists with other

* Corresponding author at: School of Information Science and Engineering, Shandong Normal University, Jinan 250014, China.
E-mail address: cluo79@gmail.com (L. Chao).

http://dx.doi.org/10.1016/j.physa.2016.01.032
0378-4371/

Please cite this article in press as: L. Chao, et al., Cooperation in memory-based prisoner's dilemma game on interdependent networks, Physica A (2016), http://dx.doi.org/10.1016/j.physa.2016.01.032

kinds of social behaviors such as competition, conflict and defection together to push forward the development of human society [1]. Hence, an understanding of cooperation among self-interest individuals is essential to reveal the evolution of social, economic and biological systems. During the past years, evolutionary game theory is applied to investigate the emergence and sustainability of cooperation in plenty of fields [2–4]. And, the prisoner's dilemma game, as one of well-known social dilemma games, is widely considered for investigating the collective behaviors among selfish individuals in repeated game [5–7].

Within the span of a decade, complex and nonlinear systems [8–13] as the research focus have been widely investigated. Thereinto, complex networks as powerful theoretical framework are used to describe and analyze realistic systems by means of abstract network models, such as epidemic spreading [14–18], dynamics of networks [19,20], communication defection [21–25], etc. Along with the deeper understanding of complex networks, interdependent networks instead of single, isolated groups have been received more attention in this research field [26]. Interdependent networks as a natural extension of the previous models are organized in two or more layers to depict the intricate variability of real complex systems, normally seen as a multilevel system, where layers influencing each other in some way could have particular features as well as relatively independent dynamical process. In recent five years, there has been increasing attention in investigating diverse properties of interdependent networks, and abundant of results have been proposed, such as dynamics of system [27–29], identification of communities [30,31] and epidemic spreading [32–34], etc. Moreover, some applications based on the structure of interdependent networks, e.g. voting networks [35], ecological networks [36] and transport networks [37] have also been proposed. Notably, evolutionary game based on interdependent networks, including the impact of biased utility on the evolution of cooperation [38], the spontaneous symmetry breaking of cooperation [39], different social dilemma implemented on integrative coupled networks [40], and optimal interdependence [41], etc., have been proposed.

In the traditional evolutionary game, players normally are assumed to be without memory, and strategies in the next round of game probabilistically depend on players' current fitness. However, as a matter of fact, when individuals make decisions, not only the current situation but also their previous experience should be involved. Some famous game strategies, such as tit-for-tat (TFT) strategy [42] and win-stay/lose-shift (WSLS) strategy [43], are both based on memory effect. Besides, in Ref. [44], the effect of memory on evolution of PDG in an isolated square lattice was discussed, where researchers found that the density of cooperators could be enhanced by memory effect in some scenarios; Horvath et al. [45] found that groups with limited memory could achieve higher level of cooperation than that with larger memory; in Ref. [46], memory effects were introduced into the PDG model under a noisy environment and the robustness of cooperation was evaluated; in Ref. [47], memory-based snowdrift game (MBSG) was presented and some non-monotonous phenomena were observed on both lattices and scale-free networks. According to the previous results, it can be concluded that the memory ability of players would be an important role to promote the level of cooperation in social dilemma. But, memory effect on evolutionary game can also be influenced by many factors, such as the length of memory, the temptation to defect and the structure of networks.

Based on the previous studies, in this article, we investigate memory effect on the evolution of cooperation in PDG game on interdependent networks. To address this problem, the memory-based PDG game is evolved on two coupled square lattices, where a certain fraction of randomly selected players have external links to the corresponding players in the other layer. To show the effect of memory and interdependence on the dynamical process of social dilemmas, two parameters are introduced. One is the memory length, M, of players, different from infinite memory [46], the accumulated fitness of individuals in the last M rounds is involved. The other parameter, ρ, is the fraction of players owning external links, which indicates the level of interdependence. We will show how the evolution of cooperation is promoted by the mutual influence of memory length of players and the level of interdependence between two layers. Then, to give insight into the evolution of social dilemma, we distinguish players in system into four different groups determined by whether having memory ability or external links. Consequently, for each kind of players, the evolutionary behaviors would be discussed. For further details with regard to the evolutionary games, update dynamics and population structure, we refer to Methods section.

This article is organized as follows. In Methods, the considered PDG model, the structure of interdependent networks and the description of simulation are given. Next, we present the main results and discuss their implications. Finally, a concluding remark is given.

2. Model

The evolutionary prisoner dilemma game is staged on two coupled square lattices of size $L \times L$, both of which are assumed to be 4-neighbor networks with periodic boundary conditions. A fraction, ρ, of players are selected at random to connect with the corresponding players residing on the other layer by external links. The parameter, ρ, determines the level of interdependence between two lattices. For easier reference, players owning external links are referred as "distinguished players", and the rest which only have internal links to its four neighbors on the home network are called as "ordinary players". To make comparative study with the previous works, the weak prisoner's dilemma game is adopted [48], where the reward for mutual cooperation $R = 1$, the temptation to defect $T = b$ $(1 < b < 2)$, the punishment for mutual defection $P = 0$ and sucker's payoff $S = 0$.

Initially, each player located on the vertex of the lattices is designated as a cooperator or defector with equal probability. In interaction process t, player i plays the PDG game with its four nearest neighbors on its home network and obtains the accumulated payoff p_t^i. Meanwhile, when player i has an external link, the corresponding player i' on the other layer does the

Please cite this article in press as: L. Chao, et al., Cooperation in memory-based prisoner's dilemma game on interdependent networks, Physica A (2016), http://dx.doi.org/10.1016/j.physa.2016.01.032