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Q1 Cooperation enhanced by indirect reciprocity in spatial prisoner's dilemma games for social P2P systems

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HIGHLIGHTS

- Cooperation enhanced by indirect reciprocity with the aid of spatial reciprocity.
- Prisoner's Dilemma games with three strategies including reciprocation based on image scoring.
- Incentive mechanism considering judgment errors from inaccurate evaluations of reputations.
- Investigate independent interaction and learning networks separately on the square lattice.
- Prove the critical influence of interaction networks on the evolution of cooperation.

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ABSTRACT

With the growing interest in social Peer-to-Peer (P2P) applications, relationships of individuals are further exploited to improve the performances of reputation systems. It is an on-going challenge to investigate how spatial reciprocity aids indirect reciprocity in sustaining cooperation in practical P2P environments. This paper describes the construction of an extended prisoner's dilemma game on square lattice networks with three strategies, i.e., defection, unconditional cooperation, and reciprocal cooperation. Reciprocators discriminate partners according to their reputations based on image scoring, where mistakes in judgment of reputations may occur. The independent structures of interaction and learning neighborhood are discussed, with respect to the situation in which learning environments differ from interaction networks. The simulation results have indicated that the incentive mechanism enhances cooperation better in structured peers than among a well-mixed population. Given the realistic condition of inaccurate reputation scores, defection is still successfully held down when the players interact and learn within the unified neighborhoods. Extensive simulations have further confirmed the positive impact of spatial structure on cooperation with different sizes of lattice neighborhoods. And similar conclusions can also be drawn on regular random networks and scale-free networks. Moreover, for the separated structures of the neighborhoods, the interaction network has a critical effect on the evolution dynamics of cooperation and learning environments only have weaker impacts on the process. Our findings further provide some insights concerning the evolution of collective behaviors in social systems.

1. Introduction

Recently, P2P (Peer-to-Peer) technology has been applied extensively in the fields of file sharing, video streaming and instant communication. The success of these applications ultimately depends on whether users actively contribute

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resources. However, most peers refer to be free riders who enjoy services from others, but they are reluctant to provide anything themselves. It has been reported that 85% of users in Gnutella P2P platforms download files repeatedly and that only 1% of their peers spontaneously share new files [1]. The free-riding phenomenon seriously damages the performances of P2P systems [2]. For example, it might limit the availability and diversity of services, degrade the efficiency of resources search and relay.

Game theory provides a classic frame to analyze such selfish behaviors in both human society and online systems. Since rational peers are driven by their own interest at the expense of social welfare, non-collaborative behaviors usually dominate P2P systems, as the paradigm of the Prisoner's Dilemma (PD) game teaches us [3]. From an evolutionary perspective, altruistic peers are always exploited by free-riders and defection is the unique evolutionary stable strategy among a well-mixed population [4–6]. Especially in complex P2P networks, cooperation hardly ever emerges and survives among unstructured peers without any social enforcing mechanisms.

Reciprocal altruism mechanisms have been widely developed to motivate collaboration simultaneously for P2P applications. In the BitTorrent protocol, free-riders are usually restrained by the choking algorithm based on Tit-For-Tat (TFT) [7]. Since TFT is vulnerable to noise, such mechanism of direct reciprocity hardly provides robustness in P2P systems where information is usually incomplete and inaccurate [8–10]. In contrast, indirect reciprocity is more practical and scalable in the environments with large and dynamic memberships [11,12]. Without limitation of repetitive interaction, indirect reciprocity does not emphasize mutual interest of peers concerning the owned resources. Under the incentive mechanism, individuals help others with higher reputations and they, in turn, gain good reputations if they behave cooperatively. Nowak was the first to study indirect reciprocity by image scoring and presented its evolutionary stability on the specified conditions [13]. On the foundation of the classic theory model, some reputation algorithms [14–16] have been investigated extensively. In these practical model, the validity of the reputation assessment depends on the objective reporting and integral information. However most of such algorithms provide unsatisfactory and unrealistic results relative to autonomous and large scale networks. This is due to the fact that inaccurate reputation scores may be evaluated based on unrelated transactions or by strangers in the large scale P2P systems.

Many social P2P applications have attracted significant attention recently where social information of peers may be exploited to improve the performances, i.e., accelerate the efficiency of content discovery, enhance availability of file sharing systems, and strengthen the security and stability of P2P networks [17–19]. Torrents on Twitter, for example, has been proved to achieve a better degree of sharing by utilizing the stable relationships among users [20]. In addition, existing P2P stream video platforms, such as PPStream, recommend that users to combine their accounts with social networks applications. On the basis of the social property that friendship fosters cooperation [21], the relationships of peers can been utilized to encourage collaborative behaviors, since defection hardly invades cooperation clusters according to spatial reciprocity [22]. In social P2P systems, interactions frequently take place among acquaintances rather than within the unstructured population. It is consistent with the circumstances of spatial reciprocity when interactions are restricted among neighbors underlying some types of networks structures.

After the pioneer study of spatial reciprocity [22], abundant seminal research has been concentrated on the effects of topology structure [23–26], and the various underlying mechanisms have been explored extensively [27–35]. Most of them assume that an individual interacts with its near neighbors and then adjust its strategy by learning from the same neighbors. Ifti first studied the continuous PD game when the interaction neighborhood (IN) and the learning neighborhood (LN) are different [36]. Related works have declared that the separation of LN and IN can dramatically affect the evolution of cooperation [37–39]. Actually, in social P2P systems, peers prefer to share resources locally with friends or within their communities, but they can learn profitable strategies from others in the whole networks. In addition, peers with limited abilities of cognition only observe and imitate behaviors of their acquaintances, even though they have global opportunities to deal with any peer. Therefore, it is interesting to investigate further the impact of breaking the congruence of the interaction and learning networks in realistic social P2P environments.

Since both indirect reciprocity and spatial reciprocity enhance cooperation, reputation mechanisms that rely on social networks have been of concern in recent years. Social P2P reputation management may aggregate available feedback effectively with low overhead and achieve robustness against possible misbehaviors [40,41]. Stochastic evolution of such mechanism has proved that network structure favors reciprocation within finite population [42]. However, the theory conclusions irrespective of specific reputation model hardly correspond with the situations in practical P2P systems exactly.

Inspired by these works, we aim to investigate P2P incentive mechanism that incorporates indirect and spatial reciprocity. Our study focuses on how the network structure affects the evolution of cooperation in reputation systems. An extended spatial PD game with three strategies has been constructed on interdependent interaction and learning networks. Unlike similar research [42,43], repeat interactions are restricted strictly during the evolution process based on indirect reciprocity. Second, judgment errors in reputation systems are admitted when reciprocators distinguish partners by their reputations on image scoring. Moreover, the effect of separated networks is explored for the social P2P platforms. The results of Monte Carlo simulation verify that the incentive mechanism promotes cooperation more effectively in structured peers on a regular lattice than among a well-mixed population. Similar conclusions have been drawn on lattice networks with different sizes of neighbors and on various underlying networks, including scale-free and regular random networks. Further, temporal and spatial results declare that the structure of interaction neighborhoods dramatically influence the process and the stationary results of evolution. In the rest of this paper, we first describe our model, next present the results and discussion, and finally draw our conclusions.

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