Applied Mathematics and Computation 251 (2015) 192–202

Contents lists available at ScienceDirect

Applied Mathematics and Computation

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

Impact of individual response strategy on the spatial public goods game within mobile agents

Mei-huan Chen [a,b], Li Wang [a,b], Juan Wang [c], Shi-wen Sun [a,b], Cheng-yi Xia [a,b,*]

[a] Tianjin Key Laboratory of Intelligence Computing and Novel Software Technology, Tianjin University of Technology, Tianjin 300384, PR China
[b] Key Laboratory of Computer Vision and System (Ministry of Education), Tianjin University of Technology, Tianjin 300384, PR China
[c] School of Electrical Engineering, Tianjin University of Technology, Tianjin 300384, PR China

ARTICLE INFO

Keywords:
Public goods game
Individual response strategy
Mobile agents
Evolution of cooperation

ABSTRACT

The management and deployment of public resources has become an active topic within scientific communities, and attracted the substantial attention from a great number of interdisciplinary researches, including social, natural, biological sciences and economics. Among them, public goods game provides an effectively theoretical framework to deeply understand the evolution of collective cooperation and to solve this challenging problem. In this paper, we investigate the cooperative behaviors among mobile agents which are located on a sparse square lattice and can make an estimate on the current situations for themselves, and we put forward several models considering different mobility rules and strategy update order to further model real scenarios. Large quantities of simulations indicate that strategy update order can obviously change the evolution of collective cooperation, but the mobility rule can play a different role for a specific update order in our models. Current results will be of high relevance to deepen our knowledge on the cooperation mechanisms within realistic and mobile circumstances.

1. Introduction

Within natural, social or biological systems, the persistence or sustainability of cooperation has been an open challenge among the scientific communities, which has been analyzed or understood by using different theoretical tools from diverse disciplines, ranging from biological and social sciences to statistical physics [1]. Among them, the evolutionary game theory (EGT) [2] has been firmly established as one of the strongest tools to understand the emergency of cooperation, and to analyze various dilemmas in which the conflicts or paradoxes between selfish individuals are often modeled as the pair-wise game models [3], such as prisoner's dilemma game (PDG) [4–14], snowdrift game (SDG) [15–19], traveler's dilemma game [20,21]. In these models, the collective cooperation is still ubiquitous under real-world scenarios although defection is often an evolutionary stable strategy (ESS) in theory. Thus, identification of effective means to drive the population to cooperate becomes much more significant, and several archetypical mechanisms, which include kin selection [22], direct or indirect reciprocity [23–25], group interactions[26], spatial and network reciprocity [27–33], have been considered as the powerful ways to promote the evolution of cooperation within the structured populations.

* Corresponding author at: Tianjin Key Laboratory of Intelligence Computing and Novel Software Technology, Tianjin University of Technology, Tianjin 300384, PR China.

E-mail address: xialooking@163.com (C.-y. Xia).

http://dx.doi.org/10.1016/j.amc.2014.11.052

In reality, many resources, minerals, pastures and even public services are often maintained and shared within multiple players, in which individual and collective interests are perhaps paradox and even the tragedy of the commons arises [34]. Again, the EGT provides the public goods game (PGG) as a classic paradigm for the study of various aforementioned social dilemmas, and several schemes have been proposed to enhance the cooperation over the past years when compared to the traditional PGG within well-mixed [35] or structured populations [36]. For instance, reward and punishment [37–39], investment heterogeneity [40] and reputation [41] are incorporated into the PGG model, to a greater extent, to clarify the public cooperation behaviors. In addition, the inclusion of spatial structure or complex heterogeneous interactions between agents is also proved to be a powerful means to facilitate the evolution of public cooperation [42–44]. It is worth mentioning that in rapidly developing modern societies individuals often leave the current environments, whether actively or passively, to study or work on another place. Thus, the behavior playing the game under the mobile scenarios has also attracted extensive concern, and individual mobility has been added into the evolutionary models, indicating that the cooperation can still be sustained collectively.

For the games played by mobile agents, an intriguing work is that Roca & Helbing [45] propose a PGG model to illustrate the emergence of social cohesion in a model society of greedy and mobile individuals, and find that the cooperation can be promoted with very low, even zero information requirements about other neighboring agents and without any imitation. Starting from this work, Xia et al. [46] incorporated the environmental knowledge into the PGG model, and put forward several classes of PPG game models considering different kinds of information about competing and neighboring players in which the behavior of public cooperation within a spatially sparse network composed of mobile agents is investigated in detail. However, in the original model, an unsatisfactory individual decides to move or change her current strategy with two independent probability test, one for the movement at first and the other for the strategy successively. In the revised work, the authors allow an individual to only have a chance to move or change the current strategy with a specific probability in the model of class **III**. That is, the above-mentioned works did not consider the impact of the order between the individual motion and changing strategy on the public cooperation. As pointed out in Ref. [47], the authors show that the order of individual diffusion can remarkably influence the cooperative behaviors in the spatially sparse lattices under the simplified PDG environments. Therefore, in this work, we will discuss the role of movement order in the public goods game along the line of Ref. [46] which cannot consider the order of strategy update and individual mobility, and we find that different mobility and update polices can create the distinct results.

The rest of this work is structured as follows. In Section 2, the modified PGG models within mobile agents are clearly presented. Section 3 gives the extensive simulation results. At last, some concluding remarks are clarified in Section 4.

2. Models

2.1. PGG model within mobile agents

We simulate the public goods game on a model network which is an $L \times L$ square lattice with periodic boundary. If an $L \times L$ square lattice is considered, the number of nearest neighbors is no more than 8 (*i.e.*, Moore neighborhood). Firstly, N agents are randomly placed on the cross points of the regular lattice. To note that, the number of agents N is less than L^2 and the density of individuals in the network $\rho = N/L^2$ is less than 1 (i.e., $\rho < 1$). Thus, one agent can move from one site to another neighboring site which is not occupied by any other agent. Each individual has 8 nearest neighbors at most and the specific number of neighbors depends on the occupied sites around him.

Then, each individual i will play the PGG with his effective nearest neighbors (*i.e.*, the neighboring occupied sites). If the number of effective nearest neighbors of a focal player i is written as k_i, then $0 \leqslant k_i \leqslant k_{max} = 8$ and player i will participate in $k_i + 1$ games, in which one PGG group centers around himself and other k_i PGG groups focus on his k_i nearest neighbors. In the public goods game, there is a public pool and all players can volunteer to decide whether they will donate their own funds into that pool. If some individuals choose to invest (usually, making a unit contribution $C = 1$), they are called cooperators (**Cs). On the contrary, if players contribute nothing, we term them as defectors (**Ds). After that, the total investment is multiplied by a synergy factor $r\,(r \geqslant 1)$ which means a kind of inspiring effect for the cooperation, and the multiplied investment will be equally distributed among all participants involved in this PGG group. As an example, there exists a PGG group with n_c cooperative agent within totally n players, the payoff of Cs or Ds. can be calculated as follows,

$$\begin{cases} \pi_C & = r \times \frac{n_c}{n} - 1, \\ \pi_D & = r \times \frac{n_c}{n}, \end{cases} \tag{1}$$

where π_C or π_D denotes the pure income of cooperator or defectors from the current game group. In order to compute the total payoff of an individual, we will accumulate all the incomes from each PGG group in which a focal player participates. Obviously, from the perspective of individuals, cooperators will be an disadvantageous status when compared to defectors, since Cs need to pay a cost $C = 1$ for the cooperation in one PGG group. However, if all participants can contribute nothing to the PGG group, every player will not get anything during a round of game. On the contrary, everyone will obtain much higher income if all players are willing to pay for the cost $C = 1$ (that is, cooperation). Thus, a dilemma arises and additional promoting schemes need to added into the evolution of individual strategies, such as volunteering, reward or punishment.