Physica A 389 (2010) 1090–1098

Contents lists available at ScienceDirect

Physica A

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

Cooperation and charity in spatial public goods game under different strategy update rules

Yixiao Li [a,b], Xiaogang Jin [a,b,*], Xianchuang Su [a], Fansheng Kong [a], Chengbin Peng [a]

[a] *Institute of Artificial Intelligence, College of Computer Science, Zhejiang University, 310027, PR China*

[b] *Ningbo Institute of Technology, Zhejiang University, 315100, PR China*

ARTICLE INFO

Article history:
Received 6 July 2009
Received in revised form 3 September 2009
Available online 13 November 2009

PACS:
02.50.Le
87.23.Ge
87.23.Kg

Keywords:
Evolutionary game theory
Altruism
Egalitarianism
Lattice
Random selection rule
Threshold selection rule

ABSTRACT

Human cooperation can be influenced by other human behaviors and recent years have witnessed the flourishing of studying the coevolution of cooperation and punishment, yet the common behavior of charity is seldom considered in game-theoretical models. In this article, we investigate the coevolution of altruistic cooperation and egalitarian charity in spatial public goods game, by considering charity as the behavior of reducing inter-individual payoff differences. Our model is that, in each generation of the evolution, individuals play games first and accumulate payoff benefits, and then each egalitarian makes a charity donation by payoff transfer in its neighborhood. To study the individual-level evolutionary dynamics, we adopt different strategy update rules and investigate their effects on charity and cooperation. These rules can be classified into two global rules: random selection rule in which individuals randomly update strategies, and threshold selection rule where only those with payoffs below a threshold update strategies. Simulation results show that random selection enhances the cooperation level, while threshold selection lowers the threshold of the multiplication factor to maintain cooperation. When charity is considered, it is incapable in promoting cooperation under random selection, whereas it promotes cooperation under threshold selection. Interestingly, the evolution of charity strongly depends on the dispersion of payoff acquisitions of the population, which agrees with previous results. Our work may shed light on understanding human egalitarianism.

1. Introduction

Cooperation prevails in the real world, ranging from unicellular organisms to unrelated human individuals. Understanding the emergence and persistence of cooperative behavior among selfish individuals is an important issue in many fields of both natural and social sciences [1,2]. When studying cooperative behavior in the context of evolution, people often resort to evolutionary game theory as a common framework and strategic games as a metaphor of the interplay between individuals [3,4]. In a simple strategic game, e.g. prisoner's dilemma game (PDG) and public goods game (PGG), players have the choices of cooperation and defection. A player maximizes its benefits by taking one of these two strategies. A defector can exploit a cooperator's benefit, so players should take the defection strategy. Therefore, the 'rational' strategy is to defect and it causes the 'free-rider' problem or the 'tragedy of the commons' [5]. Several mechanisms have been proposed for the evolution of cooperation [6]. In a seminal article, Nowak and May [7] introduced spatial structure as the framework on which evolutionary games take place. Located on the sites of a square lattice, players are constrained to play PDG only

* Corresponding author at: Institute of Artificial Intelligence, College of Computer Science, Zhejiang University, 310027, PR China. Tel.: +86 13705815020.
E-mail address: xiaogangj@cise.zju.edu.cn (X. Jin).

0378-4371/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.physa.2009.11.010

with their immediate neighbors. They found out that the cooperators are now able to resist invasion of defectors. The effect of spatial structure on cooperation is called network reciprocity. In the past few years, this field has been spurred by plenty of discoveries on how different structures of interactions can affect and enrich the outcome of evolutionary games (see the review [8] and references therein).

Human cooperation is more puzzling than cooperation among individuals of other creatures, because humans exhibit complex behaviors in the evolution of cooperation [9–11]. Exploring the coevolution of cooperative and other human behaviors is important to understand how humans differ from animals and the origins of humanity. Humans have more advanced cognitive capacity than animals and exhibit various kinds of prosocial behaviors. Ethnographic and experimental studies have demonstrated that humans are strongly shaped by egalitarianism, the preference for equality [12,13]. Humans have egalitarian motives even when there is no cooperative behavior to be reinforced [14]. Human egalitarian preference is developed during childhood [15]. A recent study on distributive justice demonstrates that a sense of fairness is rooted in emotional processing [16]. Egalitarianism also helps to understand human's engagement in punishing selfish individuals [17,18]. As we know, punishment is an effective way to sustain cooperation and the coevolution of punishment and cooperation has drawn wide interest recently [10,11,19–23]. However, punishment is not as efficient as indirect reciprocity [24] and may cause the problem of punishing good ones [25]. Furthermore, egalitarian behaviors are not merely punishment. Out of egalitarian motives, humans can transfer their welfare to their fellows who are inferior. Actually, this kind of welfare transfer is more natural than punishment and ubiquitous in human societies. Moreover, it is costless without the sacrifice of overall benefits. We use the term 'charity' to describe this behavior. Previous studies on charity are usually experimental or empirical ones [26–28].

We study the coevolution of charity and cooperation from a game-theoretical point of view. Individuals are located on lattice with neighbors involved in the interactions of game playings and charity actions. An egalitarian individual donates to the one whose payoff is less than its and the lowest in the donor's neighborhood after the game interactions. The effects of different strategy update rules on the coevolution are studied. Under random selection rule that individuals randomly update their strategies by imitating, charity is incapable in promoting cooperation. Further, we adopt threshold selection rule to mimic those situations where the worst individuals in the whole population should update their strategy. Charity can promote cooperation under threshold selection. Another interesting result is that threshold selection rule can lower the threshold for cooperation, whereas random selection rule can enhance the cooperation level. Further analysis shows that the persistence of charity strongly depends on the payoff dispersion of the population.

The article is structured as follows. Section 2 describes the spatial PGG and our definition of individual charity behavior. In Section 3, we present the individual-level evolutionary dynamics of our model and different strategy update rules. Then, we study the coevolution under these rules. In Section 4, we discuss the sociological implications of the results and summarize our findings.

2. Spatial public goods game with charity

2.1. Spatial public goods game

Public goods are essential elements for every society, e.g. sheltering, hunting, defense. For this reason, PGG is developed and often taken as a metaphor for the problem of human cooperation [4]. In the experimental settings of PGG, an experimenter asks n players to invest some money into a common pool. All players know that the total amount is multiplied by a multiplication factor r (usually $1 < r \leq n$), and divided equally among the n players, irrespective of their contribution. Each altruist (A) contributes an amount c to the public goods; Selfish individuals (S) do not contribute. Usually, c denotes the cost of cooperation, i.e. the invested money. In a mathematical formulation, the payoffs for altruists P_A and selfish individuals P_S are then given by $P_S = (rn_Ac)/n$ and $P_A = P_S - c$, where n_A is the number of altruists in the group and n is the size of the group.

As we have mentioned in the previous section, interactions between different individuals may not be random, but structured. If a player has interaction with another, an edge is formed. An interaction structure defined by a square lattice has often been studied and the spatial version of PGG is thus developed [7,8,19,29,30]. Confined to a site on the square lattice, each player interacts only with its four nearest neighbors (von Neumann neighborhood). Thus, the group size $n = 5$. If a player hosts a game, all its linked players must take part in the game. We do not consider the situation in which players voluntarily take part in the game. The payoffs obtained by the participants of the PGG hosted by player i are:

$$P_S(i) = (rn_A(i)c)/n \tag{1}$$

$$P_A(i) = P_S - c. \tag{2}$$

A player hosts game, and takes part in other games hosted by its neighbors. The payoff function for player i is:

$$f(i) = P_x(i) + \sum_{j \in \mathcal{N}_i} P_x(j) \tag{3}$$

where the payoff sum for player i runs over all the games it plays. $\mathcal{N}_i$ is the set of neighbors of i. $x \in \{A, S\}$ is the strategy of player i involved in the game. As the result of spatial effect, there is a phase transition that cooperation persists when r is big enough.