Physica A xx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Physica A

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

ELSEVIER

Q1 Promotion of cooperation by payoff-driven migration

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HIGHLIGHTS

- We propose a payoff-driven migration in which the velocity of an agent depends on his/her payoff.
- The lower the payoff is, the faster the moving speed is, and vice versa.
- The cooperation level is markedly enhanced.

ARTICLE INFO

Article history:
Received 13 September 2015
Received in revised form 3 January 2016
Available online xxxx

Keywords:
Cooperation
Migration
Evolutionary game

ABSTRACT

Migration plays an important role in the evolution of cooperation. Previous studies concerning mobile population often assumed that all agents move with the identical velocity. In this paper, we propose a payoff-driven migration in which the velocity of an agent depends on his/her payoff. A parameter α is introduced to adjust the influence of payoff, when $\alpha = 0$ means that agents all move with the identical velocity while $\alpha > 0$ means that the lower the payoff is, the faster the moving speed is, and vice versa. For the prisoner's dilemma game, we find that in comparison with the case that agents all move with the same speed, cooperation could be promoted strongly when payoff-dependent velocity is considered. Remarkably, the cooperation level is not a monotonic function of α, and there exists an optimal value of α which can lead to the maximum cooperation level. For the snowdrift game, the cooperation level increases with α.

1. Introduction

Cooperative behavior is ubiquitous in both natural and social systems [1]. So far, the evolutionary game theory has provided a mathematical framework [2,3] to address the emergence of cooperation. The prisoner's dilemma game (PDG) and the snowdrift game (SG) are employed frequently to investigate the emergence of cooperation within groups of selfish individuals [4–14]. Many important mechanisms have been proposed to explain the emergence of cooperation, such as kin-selection [15], direct and indirect reciprocity [16–18], group selection [19,20], social diversity [21–23], reward and punishment [24–26], and coevolution of strategy and structure [27–31]. More details about spatial evolutionary games are discussed in Refs. [32–37] and references therein.

As the rapid development of complex network theory [38–42], much effort has been devoted to evolutionary game on complex networks in the past decade [43–56], where the nodes represent individuals and links represent social

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http://dx.doi.org/10.1016/j.physa.2016.01.027
0378-4371/© 2016 Published by Elsevier B.V.

relationships, such that individuals are constrained to play only with their immediate neighbors. In a statically structured population, individuals' neighborhoods are fixed. However, in the case of migration, individuals can change their neighborhoods. As is well known, migration is a common and essential feature presented in animal world and human society. For example, every year millions of animals migrate in the savannas of Africa and every day thousands of people travel among different countries. Recently, mobility has attracted considerable attention as it greatly affects cooperation in spatial games [57–68].

Previous studies often assumed that agents all move with the identical velocity, which seems a little unrealistic. In this paper, we introduce a payoff-driven migration, where the velocity of an individual is determined by his/her payoff.

The following of this paper is organized as follows. The model and methods, including descriptions of evolutionary processes, are presented in Section 2. In Section 3, we show the experimental results. In Section 4 we summarize our findings and discuss the social implications of this work.

2. Models and methods

Following the previous study [59], the simulations in this paper are carried out on a two-dimensional square plane of size $L \times L$ with periodic boundary conditions, where agents simultaneously move and play games. Initially, N agents are randomly assigned on the plane, and a direction is randomly chosen for each agent with uniform probability in the interval $[-\pi, \pi]$.

The three main ingredients of the model are the rules of the motion, the definition of the graph of interactions, and the rules of the evolutionary game.

2.1. Motion

Unlike previous studies, agents move with different velocities in our model. At each time step, the position of agent i is updated according to

$$\begin{cases} x_i(t+1) = x_i(t) + v_i(t)\cos\theta_i(t) \\ y_i(t+1) = y_i(t) + v_i(t)\sin\theta_i(t) \\ v_i(t) = v_0 \mathrm{e}^{-\alpha p_i(t)}. \end{cases} \tag{1}$$

where $x_i(t)$ and $y_i(t)$ are the coordinates of agent i at time t, $p_i(t)$ and $v_i(t)$ are the payoff and velocity of agent i at time t, respectively. Absolute velocity v_0 is a key parameter characterizing the intensity of population mobility. Generally speaking, larger v_0 means higher mobility, and vice versa. $\alpha(\alpha \geqslant 0)$ is a control parameter responsible for the dependence of the moving speed, $v_i(t)$, on the payoff, $p_i(t)$. When $\alpha = 0$, all agents move with an identical velocity. When $\alpha > 0$, the agent with low payoff always moves with a high velocity, and vice versa. This definition of velocity is reasonable in terms of the instinct of seeking advantageous and avoiding disadvantageous living habitats.

2.2. Network of interactions

Each agent has the same communication radius R at time t, two agents i and j can play game with each other only if the distance between them is less than R,

$$d_{i,j}(t) = \sqrt{[x_i(t) - x_j(t)]^2 + [y_i(t) - y_j(t)]^2} < R, \quad (j \in \Omega_i(t), j \neq i) \tag{2}$$

where $\Omega_i(t)$ denotes the neighbors set of the agent i at time t.

2.3. Evolutionary dynamics

Our study is carried out for the PDG and SG. PDG and the SG are commonly used two person games with two strategies, cooperation (C) and defection (D). Mutual cooperation pays each a reward R, while mutual defection brings each a punishment P. When one defector meets one cooperator, the former gains the temptation T while the latter obtains the sucker's payoff S. The payoff rank for PDG is $T > R > P > S$. As a result, in a single round of PDG it is best to defect regardless of the opponent's decision, but the collective payoff achieves the maximum only when both players cooperate, hence the dilemma arises. For SG, the payoff rank is $T > R > S > P$. Thus, in the SG the best action is to take the opposite strategy of the opponent: to defect if the other cooperates, but to cooperate if the other defects. Note in the SG, the average population payoff at evolutionary equilibrium is smaller than that when everyone plays (C), thus SG is still a social dilemma. To simplify, the rescaled parameters are often used in the two games. For PDG, $R = 1, T = b > 1$, and $P = S = 0$ [69]. For the SG, $R = 1, T = 1 + r, S = 1 - r$, and $P = 0$, where $0 \leqslant r \leqslant 1$ [4]. We assume that each node on a square plane represents an individual.