Physica A 514 (2019) 1–8

Contents lists available at ScienceDirect

Physica A

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

Promotion of cooperation by Hybrid Migration mechanisms in the Spatial Prisoner's Dilemma Game

Bing Li [a], Xiaowei Zhao [a,b], Haoxiang Xia [a,*]

[a] Institute of Systems Engineering, Dalian University of Technology, Dalian 116024, China
[b] School of Software Technology, Dalian University of Technology, Dalian 116620, China

HIGHLIGHTS

- Hybrid Migration mechanisms are generated by the mixture of two different migrations.
- The effects of different mixture levels on cooperation are investigated.
- Two Hybrid Migration mechanisms have different relative efficiency in supporting cooperation.
- Diversity of migration behavior plays an important role in the evolution of cooperation.

ARTICLE INFO

Article history:
Received 20 March 2018
Received in revised form 12 August 2018
Available online xxxx

Keywords:
Evolution of cooperation
Spatial Prisoner's Dilemma Game
Migration

ABSTRACT

Migration is an important factor in the Spatial Prisoners Dilemma Game. An appropriate migration mechanism can improve the level of cooperation in the system. A well-noted mechanism is success-driven migration. However, if individuals migrations are solely driven by payoff, small groups of the individuals may geographically gather into scattered clusters, resulting in the reduction of the cooperation level of the entire population. In this paper, we therefore investigate whether this problem can be resolved by respectively mixing the success-driven migration with two additional migration mechanisms to form two new hybrid migration mechanisms. The first means of hybridization is to mix with the Mean-payoff-driven migration, in which an individual migrates to its first-order neighboring site when its payoff is less than the mean payoff of the whole population. The second means is to mix with the Escaping-defector-driven migration, in which an individual migrates according to the number of defectors among its neighbors. We compare these two hybrid mechanisms with the original migration mechanism that combines the success-driven and random-driven migrations. The simulation results show that the hybrid mechanisms we proposed can effectively eliminate the betrayal clusters and the cooperation level of the system can noticeably be improved. The effect of improving the cooperation level is more significant in case that the initial population is sparse.

1. Introduction

Cooperation is a prevalent phenomenon in both social and biological systems. Evolutionary game theory [1,2] provides a fundamental framework for the research of the evolution of cooperation. The prisoner dilemma game (PDG) has been a widely used metaphor for understanding cooperation between selfish individuals [3–9]. Many important mechanisms have

* Corresponding author.
E-mail address: hxxia@dlut.edu.cn (H. Xia).

https://doi.org/10.1016/j.physa.2018.09.018
0378-4371/

been proposed to explain the emergence of cooperation, such as kin-selection [10], direct and indirect reciprocity [11,12], group selection [13], spatial reciprocity [14–20] reward and punishment [21,22], social diversity [23,24], and coevolution of strategy and structure [25–31].

In recent years, the migration mechanisms have attracted wide attentions. As an important factor in both nature and human society, migration plays a significant role on the emergence of cooperation. Through migration, individuals can move to their neighboring empty sites in order to achieve higher payoffs. Vainstein et al. [32] first treated empty sites as a disordering factor in a square lattice and proposed a random migration mechanism. Their work showed that individuals random movements could promote cooperation. Helbing and Yu [33] proposed success-driven migration mechanism that led towards the outbreak of cooperation in a population of selfish individuals under noisy conditions. Jiang et al. [34] proposed an adaptive migration in which individuals could move to the neighboring empty sites with probability $n_d/4$, where n_d is the number of defectors in their four adjacent sites. Yang et al. [35] proposed an aspiration-induced migration in which individuals would migrate to new sites if their payoffs were below their aspirational levels. Besides the above mentioned mechanisms, other mechanisms, such as migration driven by social welfare [36], reputation [37], and punishment [38,39], have been proposed and the results show that migration can enhance cooperation effectively [40–45].

Among the above-mentioned migration schemes, success-driven migration mechanism is a well-noted mechanism, in which an individual explores the expected payoffs for the empty sites in the neighborhood. If the fictitious payoff is higher than the payoff in the current location, the individual is assumed to move to the site with the highest payoff; otherwise, it stays put. However, this mechanism may cause a problem that small groups of individuals would aggregate geographically into scattered clusters, if everyone migration is solely driven by payoff. This would affect the widespread dissemination of cooperative strategies and limit the overall cooperation level of the entire population.

In order to solve this problem, we explore the Hybrid Migration (HM) in this paper. The Hybrid Migration is a mixture of two different migration mechanisms. In both nature and human societies, the motivation for individual migration is not constant. Individuals have to leave their residence for predators or food shortages; or may move for better place. The reasons of migrating behavior in animals and humans are diverse and keep changing according to circumstances. Under HM, an individual will execute either the success-driven migration or some alternative migration mechanism with a certain probability. Here we propose three HMs, namely *Mean-payoff-driven HM (MHM), Escaping-defector-driven HM (EHM)* and *Random-driven HM (RHM)*. We carry out simulation experiments to observe individuals evolutionary processes under different migration mechanisms. We find that HM can promote cooperation for a larger range as compared with the standalone success-driven migration, which we call *Pure Success-driven Migration (PSM)* when individuals only follow the principle of maximizing their payoffs when migrating. In addition, three HMs have different functions on the evolution of cooperation.

The remainder of this paper is organized as follows. The introduction of the model is given in the next section. In Section 3, we present the simulation results and analysis. Finally, we summarize our findings and give the conclusion.

2. Model

In this paper we use the Spatial Prisoner Dilemma Game (SPDG) to carry out our research. For the payoff matrix seen as Formula (1), we set $T = 1 + r$, $R = 1$, $P = r$ and $S = 0$. Here r $(0 \leq r < 1)$ represents the ratio of cost to benefit of cooperation in the game [46].

$$M = \begin{pmatrix} R & S \\ T & P \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 1+r & r \end{pmatrix} \tag{1}$$

The population in the game is placed on a square lattice of $L \times L$, which satisfies the periodic boundary. Each individual occupies a site on the lattice and has eight neighbors in the *Moore Neighborhood* [47]. The population is randomly distributed on the lattice. The density of population is d_0, which means that d_0 proportion of the lattice is occupied by individuals while the rest part of the lattice is empty. At the beginning of the evolution, each individual adopts the strategy of half-C-and-half-Dstrategy (C for Cooperate, and D for Defect), viz., with probability 0.5 to cooperate.

At each time step, the evolution of all individuals on the lattice consists of three steps, i.e., gaming, strategy updating and migration. Firstly, each individual plays the Prisoner Dilemma Game (PDG) with its 8 direct neighbors respectively and gains its payoff according to Formula (1). Then the individual updates its strategy according to the rule of imitatingCthe-best, in which the individual compares its own payoff with the payoffs of the 8 neighbors and replaces his current strategy with the strategy of the neighbor who has the highest payoff. Finally, all the individuals change their locations according to the migration mechanism of the system. In this paper, three HM mechanisms are investigated. Each HM mechanism is formed by mixing the success-driven migration with another specific migration mechanism. The single migration mechanisms are described as follows.

(a) Success-driven Migration. When an individual performs the success-driven migration, it will first calculate the expected payoffs of its first-order neighbors and compare its current payoff with the highest expected payoff. If the highest expected payoff is larger, the individual will migrate to that empty site. Otherwise, the individual will not move.

(b) Mean-payoff-driven Migration. When an individual migrates according to the mean-payoff-driven migration, the chosen individual calculates the average payoff of all the individuals on the lattice, viz. the global mean payoff. If the individual own payoff is no less than the global mean payoff, the individual will be satisfied with its current position and