Physica A 394 (2014) 158–165

Contents lists available at ScienceDirect

Physica A

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

Adoption of different strategies in diversity-optimized populations promotes cooperation

Lei Sun [a], Dong-Ping Yang [b,c,*]

[a] Zhicheng College, Fuzhou University, Fujian 350002, China

[b] Department of Physics, Hong Kong Baptist University, Hong Kong, China

[c] Beijing Computational Research Center, Beijing 100084, China

HIGHLIGHTS

- Adoption of multiple strategies to different neighbors by the same individual is introduced.
- We divide individuals into two types, the imitator and the responsor.
- There exists an optimal value of the proportion of responsors, leading to the highest cooperation level.
- The effects of strategy transmission rate and the connection density are also studied.

ARTICLE INFO

Article history:
Received 30 July 2013
Received in revised form 10 September 2013
Available online 30 September 2013

Keywords:
Feedback
Cooperation
TFT

ABSTRACT

In this work, a sophisticated model is proposed to study the effects of heterogeneous types of individuals on the evolution of cooperation. In the prisoner's dilemma game, the whole population which adopts different strategies against different neighbors, is divided into two types: the imitator and the responsor. The imitator updates his strategy depending on the payoffs while the responsor changes his strategies according to the other's attitude. Interestingly, it is found that there exists an intermediate value of the fraction of imitators which can guarantee the best cooperative level on the square lattice and random network. The feedback reciprocity mechanism of the responsor, the strategy transmission probability, and the connection density are also studied. Our results are helpful for understanding the specific roles played by each type of individual and the coexistence of the two groups in the real society.

1. Introduction

The emergence of cooperation represents one of the most interesting challenges in natural and social sciences [1–3]. One factor in answering this question is related to the network interaction [4–16] and population structure [17,18,12,19–22]. On the spatial topology, a cooperator can survive through the protection of compact clusters. With the fast development of complex networks recently, more attention has been attracted [23–34]. Typical examples include the effects of social diversity [35–38], impact of interdependent networks [39], age structure [40,41] and so on.

However, in all the previous studies, agents are assumed to possess the same strategy against different opponents, which is different from many realistic cases. In our society, people will take different attitudes interfering with a variety of the social factors rather than just a single one towards different opponents during interactions [42,43]. The previous model, where the individual adopts only one policy to all his neighbors, does not meet reality. Then what would happen if each individual

* Corresponding author at: Department of Physics, Hong Kong Baptist University, Hong Kong, China. Tel.: +86 852 3411 2790.
E-mail address: yangdempe@gmail.com (D.-P. Yang).

0378-4371/$ – see front matter
http://dx.doi.org/10.1016/j.physa.2013.09.042

adopts different strategies against different neighbors? In addition, there is only one type of individual (the so-called imitator) in the previous game, who judges their neighbors according to their income and continues optimizing their strategies to maximize their own interests. However, this is not necessarily the case. In the community, not only do the imitators exist, but there is also a part of responsors who usually take the strategy upon their opponents according to their opponent's strategy towards themselves rather than caring about their own income. The introduction of the responsors is an important mechanism to behavioral reciprocity in the evolution of cooperation. In the evolution, the reciprocity means: I take the same actions upon you as what you did upon me previously [44–46]. Even if the traditional reciprocity (e.g. tit for tat [45]) will promote cooperation in the repeated two-player interaction [47–51], this is not the real reciprocity in group interaction (containing more than 2 participants), because if the only way to sanction the defectors is to defect, the action also hurts other partners in the same group. An individual one-on-one feedback mechanism in our model absolutely solves the above problem. In this paper, the Prisoner's Dilemma is used to study the more realistic model of the evolution of cooperation on both the regular grid and the random networks where different strategies are utilized upon different opponents. The individuals are divided into two types: imitators and responsors. Imitators update their strategies with the Fermi probability according to payoffs. Responsors, on the other hand, take the strategy in accordance with the opponent's strategy in the last round. The impact of the two types of individuals on cooperation is studied and the reason why the structure of the coexistence of the two groups will promote cooperation in the society is investigated as well. This study facilitates us to deeply understand the evolution of society, which has a more realistic meaning.

The paper is organized as follows. In Section 2, our model is described. Results and analysis are presented in Section 3 and a brief conclusion is given in Section 4.

2. Model

Simulations of learning and direct reciprocity are conducted to study the evolution of human cooperation on 2-dimensional lattices ($L \times L$) as well as random networks. The lattice, which has the periodic boundary condition and torus-like manifold, is fully occupied with two types of players: imitator and responsor. In the simulations, players choose different strategies against different neighbors and update their strategies asynchronously [52] in two ways: either learning (imitators) or TFT fashion updating (responsor), respectively. Following common practice, both players gain 1 (0) if they cooperate (defect) with each other. When a defector comes across a cooperator, the defector gets b ($2 > b > 1$) while the cooperator gets 0 [53–56]. Initially, imitators and responsors are distributed randomly on the lattice in which the proportion of responsors is p. The initial strategy, which is cooperation (C) or defection (D), is adopted against each opponent with equal probability for both imitators and responsors. At each round, each player i plays once with all its neighbors and accumulates payoffs stored in E_i. Subsequently, an individual selected randomly updates his strategies by the following rules:

(i) If player i is an imitator, he selects a neighbor j at random and compares their cumulative returns (E_i, E_j), and the strategy against this neighbor is updated to the strategy this neighbor plays against him with probability:

$$W_{j\to i} = \frac{1}{1+\exp[\beta(E_i - E_j)]} \tag{1}$$

where β denotes the noise [57]. After successful learning, the new updated strategy will be transmitted to some of his neighbors, the number of whom is denoted as n. The ratio n/k (the degree of player i) is called the strategy transmission probability η in the following discussion.

(ii) If player i is a responsor, he randomly selects a neighbor j and updates his strategy against this neighbor by choosing the strategy this neighbor played against him in the immediate last round, that is exactly the TFT fashion updating in a two-player repeated game.

3. Results and analysis

In the following simulations, each player is placed on the 100×100 square lattice and the same results are still valid on the 200×200 lattice. Initially, strategies C and D with equal percentage are randomly distributed among the population. Individuals update their strategies synchronously. All results are obtained by averaging over the last steady 1000 MCS of the entire 10 000 MCS. Each Monte Carlo step (MCS) provides each player with a chance to update his strategies once on average. And each data is averaged by 50 runs in different initial conditions. All confrontations between any types of players are (D, C), (C, C), (D, D). The cooperation level ρ_c is the average density of the C strategy in all confrontations.

First, we study the dependence of the frequency of cooperation ρ_c on the two key game parameters, the temptation value b and the strategy transmission probability η for regular lattices in Fig. 1. It is shown in Fig. 1 that the regime of small η can provide enough payoff for an individual to sustain. With the increasing of the independence of the different strategies against different opponents realized by decreasing η to a certain degree, the cooperation enhancement can be supported to a high level at a higher defection temptation b. With lower η, the invasion of defection is reduced and cooperation is induced to be a dominant trait by the spatial reciprocity. Whereas, when η is close to 0 (see the model), which indicates no motivation to improve cooperation or defection, the cooperation level is maintained as the initial level: $\eta = 0.5$. This is due to the fact that the decreasing of η gives rise to the reduction of the aggression of strategy D. The boundary between