Chaos, Solitons and Fractals 115 (2018) 23–28

Contents lists available at ScienceDirect

Chaos, Solitons and Fractals
Nonlinear Science, and Nonequilibrium and Complex Phenomena

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

The effects of attribute persistence on cooperation in evolutionary games

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ARTICLE INFO

Article history:
Received 6 July 2018
Revised 16 August 2018
Accepted 22 August 2018

Keywords:
Cooperation
Evolutionary games
Attribute persistence
Conformity-driven
Payoff-driven

ABSTRACT

In ordinary evolutionary game theory, players update their strategies according to a certain payoff-driven rule. Szolnoki and Perc (2015) [44] found conformity-enhanced network reciprocity by introducing conformity-driven strategy-updating rule to an appropriate fraction of players. In this work, we treat strategy-updating rule as an attribute of players and allow for the evolution of the attribute, for example, the alternation of the strategy-updating rule between payoff-driven and conformity-driven rules with time. We introduce the persistence parameter T by assuming that players change their strategy-updating rules every T Monte Carlo time unit according to either unbiased rule or aspiration rule. We find that frequent alternation of strategy-updating rule improves the conformity-enhanced network reciprocity for the unbiased rule, which leads that small T greatly promotes cooperation. On the other hand, we find no improvement of conformity-enhanced network reciprocity for the aspiration rule.

1. Introduction

Cooperative behavior is ubiquitous in the real world and can be found both in natural and social systems [1]. Understanding the emergence and maintenance of cooperation among selfish individuals has drawn considerable attention from researchers across many different fields in the past decades. Evolutionary game theory provides a powerful framework for the studies of this issue [2,3]. To explore the evolution of cooperation in a population, a great number of game models, such as the prisoner's dilemma game (PDG) [4–6], the snowdrift game (SG) [7,8], the public goods game (PGG) [9,10], the stag-hunt game (SHG) [11,12] and the Ultimatum Game (UG) [13,14] have been intensively used as the paradigms to characterize pairwise or group interactions. Meanwhile, a wide variety of mechanisms have been proposed to explain the emergence of cooperation, such as direct and indirect reciprocity [15–18], punishment and reward [19–24], volunteering [25,26], aspiration [27–31], preferential selection [32,33], to name but a few.

Besides these mechanisms, considering the diversity of individuals, the effects of individuals' personal attributes on cooperation have also been intensively investigated in evolutionary games. Previous studies have shown that some attributes of individuals could promote cooperation significantly, such as reputation [34,35], migration [36,37], memory [38–40], learning ability [41–43], and so on. In recent years, one of personal attributes, conformity, has attracted much attention when modeling individuals' behavior in evolutionary games [44–49]. In real-life situations, an individual tends to follow the majority within the interaction range when adopting behavior. Such conformity might be due to herding instincts or crowd behavior in humans and social animals. Szolnoki and Perc [44] assigned a fraction of population as conformity-driven rather than pursing highest payoff. They provided firm evidence in support of conformity-enhanced network reciprocity and declared that an appropriate fraction of conformists among the population will introduce an effective surface tension around cooperative clusters and ensures smooth interfaces between different strategy domains. And then, in [45], they revealed a finding that leaders should not be conformists in evolutionary social dilemmas. Yang et al. [48] proposed a conformity-driven reproductive ability and found that, compared to homogeneous reproductive ability, conformity-driven ability can greatly enhance cooperation. Most recently, Niu et al. [49] further explored the effects of rational conformity behavior on the evolution of cooperation in PDGs. They found that, rational conformity behavior can promote cooperation in PDGs, and the greater the proportion of rational players, the more obvious the promotion of cooperation.

In previous works, Fermi function is the most widely used strategy-updating rule [50], which is based on pairwise payoff comparison and assumes that individuals pursuit highest payoff. Thus, it is called payoff-driven strategy-updating rule. On the

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https://doi.org/10.1016/j.chaos.2018.08.018
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other hand, as we have mentioned above, due to the personal attributes of individuals, they might update strategies based on conformity, which we call conformity-driven strategy-updating rule. In this work, we treat conformity-driven or payoff-driven strategy-updating rule as an attribute of individuals. The strategy-updating rule reflects the way how human choose their behaviors in the real society. In fact, people might update their strategies according to different rules at different time. It means that the strategy-updating attribute we consider here may alternate with the evolution of the strategy. Moreover, as the more realistic scenarios, co-evolutionary games have received a large amount of attention in previous works [51,52]. Inspired by these research efforts, in addition to the evolution of the strategy, we allow for the evolution of the attribute, that is, the alternation of the strategy-updating rule between payoff-driven and conformity-driven rules with time. In [53], Huang et al. investigated the effects of strategy persistence on cooperation and found that strategy persistence could promote cooperation in a population no matter what the network structure is. Here, the question we would like to address is, how the attribute persistence affects cooperation in a population after introducing the alternation of the strategy-updating rule. We wonder that, in order to achieve a high level of cooperation, whether individuals should stick to their attributes or change frequently. Motivated by previous studies, we introduce a persistence parameter T to characterize the level of attribute persistence for individuals and investigate the effects of T on cooperation.

The remainder of this paper is organized as follows. In the second section, we describe the model. Then we present the main results in the third section. Finally, we summarize the conclusion in the fourth section.

2. Model

We study evolutionary PDGs in a population of N players sitting on a square lattice with periodic boundary conditions. Each player takes either cooperation (C) or defection (D) as his strategy. In a pairwise interaction, two players receive the reward R for mutual cooperation or the punishment P for mutual defection, while a cooperator receives a sucker's payoff S when playing with a defector, which in turn receives the temptation b. In this work, we consider the weak PDG [50], such that $b > 1$, $R = 1$, $P = S = 0$.

We consider two types of strategy-updating rules, the payoff-driven rule and the conformity-driven rule. In the payoff-driven rule, the probability of player i replacing his own strategy s_i with the strategy s_j of player j is determined by the Fermi function [50]

$$W(s_i \leftarrow s_j) = \frac{1}{1 + \exp[(\Pi_i - \Pi_j)/K_p]}, \tag{1}$$

where Π_i (Π_j) denotes the payoff of player i (j) and K_p quantifies the intensity of the noise related to the replacement of strategy. The strategy-updating is most likely to happen if Π_j is greatly higher than Π_i. On the other hand, in the conformity-driven rule, player i prefers to adopt the strategy that is most common within his interaction range. The probability for player i adopting the most common strategy in his neighbourhood is described as [44]

$$W(N_{s_i} - k_h) = \frac{1}{1 + \exp[(N_{s_i} - k_h)/K_c]} \tag{2}$$

where N_{s_i} is the number of players holding the strategy s_i in the neighbors of player i and k_h is one half of the degree of player i. Similar to K_p in payoff-driven rule, K_c is also the noise intensity in the strategy updating.

In the model, we treat the strategy-updating rule as an attribute, denoted as S_U, of a player (the payoff-driven rule and the conformity-driven rule are the two options in S_U) and assume that the attribute evolves with time. We introduce a parameter T ($T \geq 1$) to characterize the persistence of individuals holding a strategy-updating rule. We assume that players will change their strategy-updating rules at time nT with a probability P_U. We consider two types of P_U. The first one is an homogeneous rule in which P_U is a constant in the range of $P_U \in [0, 1]$. $P_U = 0$ means that the population of players is partitioned into two subpopulations each with a given strategy-updating rule, and $P_U = 1$ means that every player changes his attribute S_U in every nT Monte Carlo time units for sure. The second rule is based on the aspiration and we call it an aspiration rule. The aspiration $A_i(t)$ of player i at Monte Carlo time t is defined as the average payoff of his neighbors during the last period of T. Then $A_i(t)$ can be written as

$$A_i(t) = \frac{1}{Tk_i} \sum_{j \in \Omega_i} \sum_{t'=t-T}^{t-1} \Pi_j(t') \tag{3}$$

with k_i the degree of player i and Ω_i the set of neighbors of player i. In the aspiration rule, player i will change his strategy-updating rule once his average payoff in last T Monte Carlo time units, $\langle \Pi_i \rangle (t) = \frac{1}{T} \sum_{t'=t-T}^{t-1} \Pi_i(t')$, is less than his aspiration $A_i(t)$.

We simulate the model in accordance with the standard Monte Carlo simulation procedure. Initially, the two strategies of C and D are randomly distributed among the players with equal probability and the two options of the attribute S_U, conformity-driven rule and payoff-driven rule, are assigned to players with probabilities of ρ and $1 - \rho$, respectively. One Monte Carlo time unit consists of N Monte Carlo steps and each Monte Carlo step consists of three stages. In the first stage of each Monte Carlo step, according to the random sequential update protocol, we randomly select a pair of neighboring players i and j. The players i and j accumulate their payoffs, Π_i an Π_j, by playing the PDGs with all their neighbors. Then, player i updates his strategy according to his attribute S_U. In the third stage, player i changes his attribute S_U according to the unbiased rule or the aspiration rule if the Monte Carlo time is at nT. In this work, we set $N = 10^4$, the degree of the node $k = 4$, $K_p = 0.1$ and $K_c = 0.1$.

3. Results and discussion

We first consider the model with unbiased rule for the attribute of strategy-updating rule. When the consistence $T \to \infty$ (denoted as T_∞), the model reduces to the one investigated in Ref. [44] where the population is partitioned into two subpopulations, one for conformist and the other for payoff-driven players. In Ref. [44], Szolnoki and Perc found that the presence of conformity-driven players enhances network reciprocity when the fraction of conformists within the population is neither too rare nor too common. In the other limit $T = 1$, the persistence is absent and the attribute of every player may change every Monte Carlo time. In between, the model behaves like the case with T_∞ within the Monte Carlo times $t \in [nT + 1, (n + 1)T]$ in which the strategy-updating rule remains unchanged and the fraction of conformists is constant.

Now, we investigate the joint effects of both persistence and the evolution of the attribute of strategy-updating rule on cooperation. We set the initial fraction of conformity-driven players in the population ρ to be 0.5 and $P_U = 0.5$. We monitor the fraction of cooperators f_C when the evolution of the strategy pattern reaches its steady state. Fig. 1(a) presents f_C against b for different T where each data is averaged over 300 different realizations. The cooperator frequency always falls with the temptation b increase. For the case in the absence of the evolution of the attribute S_U (T_∞), f_C departs from 1 once $b > 1$ and drops to zero at around $b = 1.27$, which exemplifies the conformity-enhanced network reciprocity in comparison with the evolutionary PDG on square lattice [56]. However, conformity-enhanced network reciprocity may be greatly im-