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Emotional decisions in structured populations for the evolution of public cooperation

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HIGHLIGHTS

- Emotions play very significant role indeed in emergence and maintenance of cooperation in structured populations in PGG.
- The influences of emotions on others are limited in the structured populations.
- Conformity, to some extent, could drive potentially more people to cooperate with higher probability.
- High-level cooperation could be promoted as increasing values of synergy factors.

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ABSTRACT

The behaviors of humans are not always profit-driven in public goods games (PGG). In addition, social preference and decision-making might be influenced, even changed by heuristics and conformity in the real life. Motivated by the facts, we would like to investigate the role of emotional system in cooperative behaviors of structured population in PGG. Meantime, the effects of diffusion of influence are studied in structured population. Numerical simulation results are indicated that emotions play very significant role indeed in emergence and maintenance of cooperation in structured populations in PGG. However, the influences of emotions on others are limited due to diminishing of influence diffusion and the existence of pure defectors. What is more, conformity, to some extent, could drive potentially more people to accept cooperative strategy with higher probability. Higher-level cooperation could be promoted as increasing values of synergy factors, but while the effects might diminish gradually as increasing number of positive heuristic players and conformist. Our work may be beneficial to address the social dilemmas in PGG.

1. Introduction

Rationality is the fundamental and primary assumption, known as "invariance", in the modern economic theory [1]. In fact, rational decision-making is challenged by the abundant experimental evidences [2–10]. In PGG, cooperators have to contribute their cost to the common pool, while defectors can achieve equal benefit without any cost [11–16]. There is a peculiar phenomena that cooperative behaviors always emerge in PGG, although defection is an optimal strategy [17–19]. These incomplete rational behaviors attract lots of attention [20,16,21,22]. In recent years, many mechanisms, which include punishment, indirect reciprocity, voluntary participation, social diversity, the critical mass, as well as conditional cooperation and success-driven mechanisms, have been explored to explain the collective cooperation [23–31].

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In recent studies, the influence of emotions on decision-making has gradually received attention. Decision-making in human society could be extremely susceptible to the presented way of options. This striking phenomenon was called "framing effect" which has been demonstrated and investigated in many different conditions [32–36]. Additionally, the importance of incorporating emotional processes within models of human choice has already been emphasized [1]. According to lots of evidences, emotions are considered as a major factor in the interaction between environmental conditions and human decision processes [37]. Some experimental results show that people may imitate some strategies which may be not further successful ways in some situations [38]. Szolnoki et al. refined the concept of imitation by imitating emotional profiles of each other instead of simply more successful pure strategies [39,40]. Through this innovative strategy imitation, higher cooperation can be promoted significantly so as to achieve higher social welfare without any additional assumptions.

Social preference, which could have a great effect on emergence of cooperative behaviors, can be an emotional factor for human behaviors. For prosocial preference, it could be improved by cooperative heuristics [41–44]. On the special environment, human behaviors might be remarkably influenced even controlled by their emotion, like herd behavior. Herding theory was described that agents prefer to imitate and follow the crowd instead of making independently decision by themselves [45–50]. Conformists could enhance network reciprocity and thus be beneficial for cooperation in the structured population [51].

Therefore, we extend the previous researches and define five types of agents, which are distributed randomly on square lattice, in our PGG model [52]. The five types of agents are including cooperator without independent thought (CN), cooperator with independent thought (CI), defector without independent thought (DN), defector with independent thought (DI), people with neutral social preference (PN). During the evolutionary process, some individuals would be conscious of serious social dilemmas in their conditions. These people, who could be called CIs, would like to call on others, especially their neighbors, to improve their environment through having effect on others' prosocial emotional system. In the PGG, DIs would always choose defective strategy to achieve more payoff. Their behaviors have negative effects on social preference of their neighbors. Normally, players (CNs and DNs) could make decisions rationally. PNs are like conformists who prefer the most common strategy. But their emotional systems may be affected by cooperative lobbying of CIs or negative behaviors of DIs. Based on above assumptions, we focus on examining effect of emotional decision on evolution of cooperation in PGG, and observing the diffusion of influence in the structured population.

Firstly, we describe rational decisions and emotional decisions in our PGG model in Section 2. Secondly, the numerical simulation results are analyzed in Section 3. Finally, conclusion is described in Section 4.

2. The PGG model with five types of agents

There are five types of agents (CIs, DIs, CNs, DNs, PNs), which are distributed on an $L \times L$ regular lattice with periodic boundary conditions. Each agent has k neighbors and attends $k+1$ PGG groups.

The payoff of each agent can be obtained between agent i and his neighbors in PGG as the following way [52]:

$$P_i = \sum_{j \in \Omega_i} P_i^j = \sum_{j \in \Omega_i} \left(r \frac{n_\alpha^j + n_\beta^j}{k_j + 1} - c_i \right) \tag{1}$$

where P_i denotes the payoff of agent i. r denotes a synergy factor. Ω_i stands for the set of PGG groups where agent i attends. The PGG group j is one of the set of Ω_i. k_j is the number of neighbors of agent i in group j. n_α^j and n_β^j stand for the number of CNs and CIs in group j respectively, c_i denotes the number of cost which agent i will donate.

2.1. Rational decision

In the system just with CNs and DNs, we assume that players are profit-driven and generally can make decision through rational system. They always pursue the maximized profit with selfish thought. In the PGG, these people will update their own strategy by imitating more successful strategy of the person who has biggest profit. For instance, one person, who chooses defective behavior in a group, can benefit more than the others who are willing to cooperate with others. In order to maximize their profits, these cooperators will change their strategies to adapt to the current environment. Therefore, agent i (i.e., CNs, DNs) would always like to follow the people who has highest payoff, if there are no CIs and DIs in their neighbors. During the intragroup interaction, the agent i will imitate the most successful strategy of agent j, who has the biggest profit, with probability using the following Fermi formula:

$$W\left(s_i \leftarrow s_j\right) = \frac{1}{1 + \exp\left[\left(P_i - P_j\right)/\mu\right]} \tag{2}$$

where μ determines the level of uncertainty by strategy adoptions. s_j is the strategy of the selected neighbor j. According to the Eq. (2), we can know that the strategy of agent with higher payoff is much easier to be adopted. In one step, all agents have one chance to update their own strategy by imitating the behaviors of their neighbors.