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Emergence of parochial altruism in well-mixed populations

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Evolution of parochial altruism is studied in a well-mixed population subdivided into two groups. Individuals' strategy is contingent on interacting partners' group property. Participants from the same group play prisoner's dilemma game, otherwise they play punishment game. We specify precisely the game parameters scope in which parochial altruism is favored for weak selection. For low mutation, we find that intergroup conflict can promote the evolution of parochial altruism. However, parochial altruism can never be favored for high mutation. We also present the conditions under which parochial altruism enjoys a higher frequency than neutral drift for intermediate mutation.

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1. Introduction

Evolutionary game theory, a key approach to analyze evolutionary dynamics, is used to explain the evolution of behaviors in various realms such as biology [25,36], physics [16] and social sciences [7,9]. The games, including Prisoner's Dilemma Game (*PDG*) [35], Public Goods Game (*PGG*) [46], Ultimatum Game (*UG*) [44] and Snowdrift Game [12], are widely used in studying the strategy's evolutionary fate. In the framework of evolutionary game, individuals in the population interact with others and gain their payoffs depending on the behaviors of themselves and the opponents.

In real world, a prairie dog gives an alarm call to tell the fellows to flee or to hide when a terrestrial predator approaches, even knowing that consequently this behavior will break the predator's plan and cause some dangers to itself. A man is probably willing to sacrifice his interests and even life to protect his companions in a conflict with opponents. These discriminative behaviors fall into the category of parochial altruism. Generally speaking, they possess the trait that the individuals are more helpful towards the ones of the same property, such as belief, community, complexion, and detrimental to the ones of different property. A remarkable characteristic of parochial altruism is that the members of the actor's group benefit as a result of one's hostile actions toward other groups [21], which is different from the tag-based cooperation, ethnocentrism and the armpit effect. Parochial altruism is widespread and easily triggered by group definition in human society. With the existence of two or more groups simultaneously, individuals are more hostile toward out-group members than in-group ones [38,34,8]. Behaviors to different individuals vary with their properties. The payoff of parochial altruist is lower than that of other members in the same group who refrain from this behavior. Parochial altruism is puzzling from an evolutionary perspective as being seemingly in conflict with Darwinian philosophy of "survival of the fittest".

To resolve this problem, increasing attention has been invested in probing evolutionary dynamics of parochial altruism [17,22,24]. Many studies have been concerned mainly on experiments or simulations [29,11,23] while theoretical studies based on analytical models are relatively rare. Individuals tend to be more cooperative to in-group members in hope of reciprocity from them [30,41]. Indirect reciprocity and reputation play an important role in the evolution of cooperation [19,43]. Individuals consider the personal reputation to decide whether and how to perform in-group favoritism [31]. Ethnocentrism and collectivism are widespread in nature. Ethnocentrism can support in-group cooperation based on shared features of an "ethnic" group without requiring mechanisms such as reciprocity, reputation, conformity or leadership [33]. Agent-based simulations in Ref. [15] have revealed that ethnocentrism can win in both early and later evolutionary stages on directed random graphs under the asexual mode of reproduction. Parochial altruism is a critical element and more common in a collectivist culture than in a universalistic culture in the minimal group situation [42].

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With the existence of parochial altruism, individuals have double standards. Comparing with cooperation with in-group members, individuals are more likely to be hostile to out-group members, such as defection, punishment, and even eviction. The experiment [17] showed that the punishers protect the violators within group much more than the ones from outside group. Meanwhile, the violators also expect the punishers, belonging to the same group, to be more lenient. However, each individual has his own expectation. Some individuals maybe tend to cooperate with everyone regardless of the group belongings. García et al. [22] have studied the evolution of parochial altruism in presence of four strategies (altruists, parochialists, traitors and egoists) for three model versions (with only assortment, with only group conflict, and with both mechanisms). The result showed that group conflict favors parochialism as well as assortment. In the study [38], population is assorted by phenotypic properties, and cooperative individuals cooperate with those who have identical or very similar phenotypes, while defectors always defect irrespective of the phenotypes of the partners. The condition, $b/c > 1 + 2/\sqrt{3}$, is presented under which cooperation is favored. Ihara [45] has studied the evolution of in-group favoritism in the context of culture-dependent discriminate sociality, and explored the possibility that the cultural transmission and resultant cultural variation can promote the evolution of discriminate sociality. In Ref. [2], the evolution of cooperation through similarity discrimination, which is independent of population viscosity and can evolve spontaneously in well mixed populations, has been studied based on agent-based simulations. Fu et al. have studied the evolution of parochial altruism with allowing strategies to change continually, and derived the conditions for in-group favoritism to be preferentially selected [13]. Further more, the paper [40] has studied the evolution of discriminative cooperation in structured populations and found that, on the contrary to the results in Ref. [14], the structural effect on the evolution of discriminative cooperation is weak. Parochialism and altruism are co-evolved and complementary. Each provides an environment favoring the evolutionary success of the other [37].

Although a lot of effort is being spent on studying the evolution of parochial altruism, the quantitative and effective condition for parochial altruism to be favored has yet to be explored. We set up a minimal model to study the evolution of parochial altruism in a well-mixed population of constant size. The population is subdivided into two groups marked by different colors visible to each individual. Strategies for each group are the same besides the visible color of group which is used to indicate the players' identity. Individuals who are parochial altruists display "In-group love" and "Out-group hate". Behavioral strategy of each individual relies on which groups his opponents come from. Put it in a specific way, players in the same group interact with each other as a cooperator or a defector. Cooperators produce benefits to others at a cost to themselves, while the defectors gain the benefit without paying out anything [1,10]. When two individuals from different groups encounter, they each can decide whether or not to punish the opponent. A punisher burdens a small cost to reduce the payoff of the punished more [20]. Intergroup punishment, which is costly for the actors to benefit the fellow members and yields no material gain, is parochial altruistic punishment. Intuitively, cooperators who do not punish the out-group members are more likely to survive since the later save the cost of executing punishment, leading to the occurrence of the "second-order social dilemma" [6]. In this model, the strategy which cooperates with in-group members and punishes the out-group members is parochial altruism with the existence of "second-order social dilemma". We specify the emergence of parochial altruism according to different mutation rates and population sizes for weak selection, and study the influences of population size and selection intensity on the evolution of parochial altruism.

2. Model

Consider a well-mixed population of constant size N with two groups marked by observable color, *Red* and *Green* respectively. Each individual interacts with anyone else equally likely. Selection dynamics can be expressed as a frequency-dependent Moran process [32], whose evolutionary dynamics can be illustrated as three elementary steps: birth, death, and replacement. The size of population remains the same. Namely, an individual is chosen to reproduce an offspring proportional to its fitness, and then a randomly chosen individual is death and replaced by the offspring. Generally, an individual with a higher fitness can be chosen to reproduce with a higher probability but it can still be eliminated due to the random drift. In this model, the Birth–Death (*BD*) updating rule [18] is adopted. At each time step, the offspring either inherits the parental strategy with probability $1 - \mu$ or mutates with probability μ, while the identity (color) of the offspring is kept identical during the replacement process. During the updating process, the offspring mutates into any other strategy equally likely, and the number of parental strategy can remain the same, increase by one, or decrease by one.

In this model, each individual can choose one of the following four strategies: parochial altruism (punishing cooperation, CP) which only cooperates with in-group partner but punishes out-group partner; non-punishing cooperation (CN_P) which only cooperates with in-group partner but does not punish out-group partner; punishing defection (DP) which both defects against the in-group partner and punishes the out-group partner; non-punishing defection (DN_P), which neither cooperates with in-group partner nor punishes out-group partner. Specially, individuals play the prisoner's dilemma game when they exhibit the same 'color' with strategies cooperation (C) and defection (D). The payoff matrix is given by:

$$\begin{array}{ccc} & C & D \\ C & b-c & -c \\ D & b & 0 \end{array}$$

Two players each receive $b - c$ upon mutual cooperation and 0 upon mutual defection. Whenever a cooperator interacts with a defector, the former gets the payoff $-c$ while the later b. As is common we set $b > c > 0$. While, they play the punishment game when they possess different 'color's with strategies punishment (P) and non-punishment (N_P). The payoff matrix is:

$$\begin{array}{ccc} & P & N_P \\ P & -\alpha-\gamma & -\alpha \\ N_P & -\gamma & 0 \end{array}$$

It means the two players each receive $-\alpha - \gamma$ upon mutual punishment and 0 upon mutual non-punishment. Whenever a punisher encounters a non-punisher, the former gets the payoff $-\alpha$ while the later $-\gamma$. As is common we set $\gamma > \alpha > 0$.

For low mutation, $\mu \to 0$, the population almost always consists of only one strategy until a mutant arises at a time. The mutant strategy competes with the resident strategy, and the fate of the mutant, either being extinct or taking over the population, is settled

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