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Evolution of cooperation in a spatial structure with compensation mechanisms

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ABSTRACT

We study the evolution of cooperation by modeling interactional individuals with compensation mechanism on a two-dimensional square lattice. In this model, the payoff to cooperators is the same no matter what types their neighbors are, while the payoff to defectors depends on whether there exists cooperative neighbor. In addition, cooperators will obtain some compensation from the payoffs of defectors. We find that a larger compensation coefficient in the model leads to the higher cooperation, which means the compensation mechanism partly promotes cooperation. In addition, the simulation results suggest that decreasing either the payoff of defectors without cooperative neighbors or the payoff of defectors with cooperative neighbors will promote cooperation.

1. Introduction

Altruistic behavior is common throughout the animal kingdom, particularly in species with complex social structures [1–6]. From a Darwinian viewpoint, the existence of altruism behavior in nature is puzzling, because natural selection should have lead animals to behave in ways that increase their own chances of survival and reproduction, not those of others [7–10]. Searching for mechanisms that can generate and sustain cooperation among selfish individuals remains to be an interesting problem [11–21].

Punishment is traditionally considered more successful than reward, however, it suffers from high costs which frequently fails to offset gains from enhanced cooperation [22]. As a result, reward is reconsidered and many reward mechanism and model have been proposed and studied. Steady and adaptive rewarding [22,23] promote public cooperation as expected, while antisocial rewarding based on akin-like pool rewarding also promote cooperation in the long term, because defectors are inclined to aggregate and unable to free-ride on the cooperators [24]. In some cases, rewarding from another population through an external link also catalyse cooperation [25].

Various game models have been introduced in regular lattices, small-world networks, scale-free networks and other complex systems [26–32]. To understand how cooperation can be favored in evolutionary game dynamics, Nowak has proposed five major mechanisms in favor of the evolution of cooperation under a wide variety of conditions, which includes kin selection, direct reciprocity, indirect reciprocity, spatial selection and multilevel selection [33].

The experimental research done on one of the typical animals, the vervet monkey, has given us some possible interpretations of it [34–37]. It is done in Amboseli National Park over a 20-month period in six groups of vervet monkeys, focusing on their group behavior. Zoologists discovered that some group members will choose to scan while others are foraging. Admittedly, the scanning monkeys have less time hunting for food during this process. However, they help reduce the risk from their predators by early alarming and assist the group to find a new foraging place in a short time. As a result, the foragers nearby can work more efficiently as there is nothing to worry about. Therefore, we sort such scanner as a cooperative one and undoubtedly, the individual with foraging behavior is a self-beneficial defector. These two behaviors are the ones we consider in our model.

Plus, as the scanners help find a better foraging space and give alarm calls, they are often allowed to forage more than others in the new field. Similarly, in the bat group, the others will try to help the warning individual raise offspring. Different from the model in which there are Reward Cooperators(RC) rewarding cooperation behaviors [22,23], the defectors there reward cooperators by themselves, which are not totally selfish.We deem all these kinds of reward as a kind of ‘compensation’ and then introduce a

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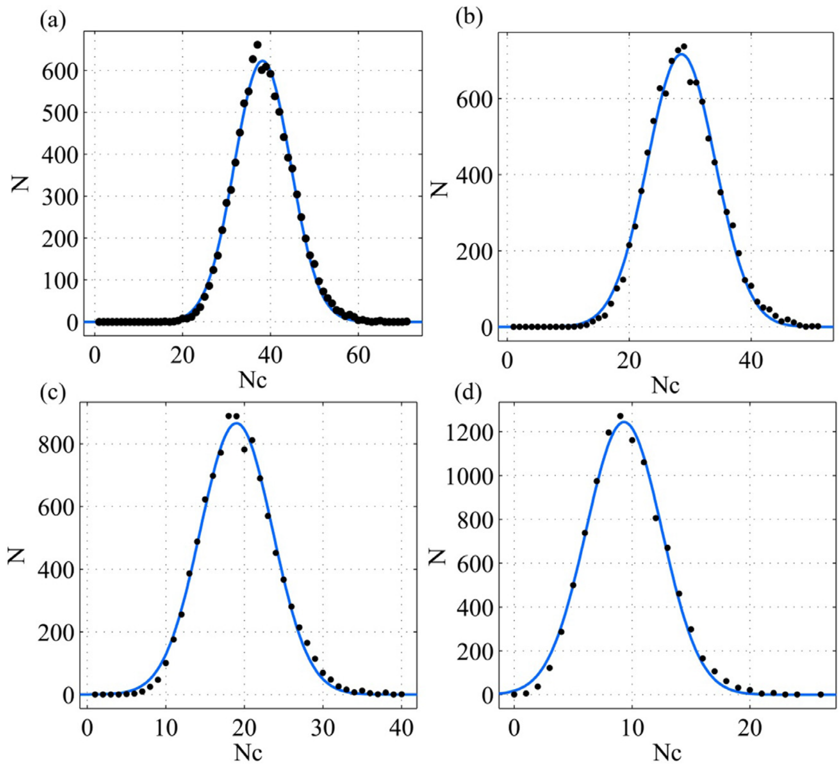

Fig. 1. Results of the number of individuals (N) who choose cooperation with different times (N_C). The points represent the simulation data, while the lines are the fitting curves. The simulation results are obtained by running 3000 times with $g_1 = 0$, $g_2 = 0.3$, $g_3 = -1$, $\alpha = 0$. (a)–(d) refer to the results in the last 400, last 300, last 200 and last 100 time steps.

relevant mechanism in our model. For simplification, we quantify this directly to the benefits of the individuals and the principle is as follows: we calculate total earnings of the cooperators and defectors, levy a certain level of benefit upon the defectors' incomes and then allocate them averagely to the cooperators. In essence, this is a promotion to the cooperation and a limitation of selfish behavior.

The paper is organized as follows: We introduce a particular evolutionary model on a square lattice in Section 2. The simulation results and discussions are shown in Section 3, while we present our conclusions in Section 4.

2. Model

We assume that individuals are located on a $L \times L$ square lattice with periodic boundary conditions. The gender difference is not considered in our model, and each individual is treated equally. There are two choices for them to choose: cooperation and defection. The system runs ~~based~~ on the following rules:

At each time step in each round of the game, if the individual is a cooperator, it obtains g_1. If the individual is a defector, how much it obtains depends on its neighbors' choices. When there exists at least one cooperator, the focal individual earns g_2, otherwise the earning is g_3. Each individual joins in a game with 9 ~~nine~~ rounds. Assuming that there are k rounds existing cooperative neighbors: A cooperator can benefit $9g_1$, while a defector can benefit $kg_2 + (9-k)g_3, k \in [0, 9]$.

We extend the model further to include a compensation mechanism. Note that the focal individual i, if it is a cooperator, we write $S_i = 0$; if it is a defector, we write $S_i = k_i g_2 + (9-k_i)g_3$. Now we give the cooperators some benefits: a cooperator can obtain another payoff except $9g_1$, which comes out of the defectors' payoffs. We denote π_i is the benefit of individual i. Therefore each individual i receives payoff:

$$\pi_i = \begin{cases} 9g_1 + \alpha \cdot \sum_{j \in L \times L} S_j / N_C & if\ i\ is\ a\ cooperator \\ (1-\alpha) \cdot S_i & if\ i\ is\ a\ defector \end{cases} \quad (1)$$

Where N_C is the number of cooperators, α is the compensation coefficient.

The fitness of the focal individual is $f = e^{\beta \cdot \pi_i}$, where β denotes the intensity of selection. Each individual will stick to its strategy or choose one of its Moore neighbors to study the Moore neighbor's strategy (cooperation or defection). Each Moore neighbor can be chosen with the probability proportional to fitness. We assume the individual m is one of i's Moore neighbors or the individual i itself, the probability of studying m's strategy is

$$p_{m \to i} = \frac{f_m}{\sum_{n \in M} f_n} \quad (2)$$

where M is the set of i and i's Moore neighbors.

It is notable that, in our model, the forager's behavior corresponds with the defector in the traditional PGG on its 'free-rider' attribute. However, the scanner there is different from the cooperator. In traditional PGG, the investment of the cooperator could be shared by all the individuals in the group. In other words, the cooperator itself could be benefited directly from this choice. However, based on the fact that the scanner could be more dangerous as they are exposed to their natural enemies, it is an entire altruistic behavior. What's more, in the traditional PGG, there exists a synergy factor [33] to represent the rewarding rate of the investment on public goods. While in our model, such factor is ignored as the foraging behavior does not bring additional direct rewards to the group. The compensation is also different from the traditional PGG as it is not from a public pool but the defector.