Effects of compassion on the evolution of cooperation in spatial social dilemmas

Yumeng Li [a,b], Jun Zhang [a,b,*], Matjaž Perc [c,d,e,**]

[a] School of Electronic and Information Engineering, Beihang University, Beijing 100191, PR China
[b] National Key Laboratory of CNS/ATM, Beijing 100191, PR China
[c] Faculty of Natural Sciences and Mathematics, University of Maribor, Koroška cesta 160, SI-2000 Maribor, Slovenia
[d] CAMTP – Center for Applied Mathematics and Theoretical Physics, University of Maribor, Mladinska 3, SI-2000 Maribor, Slovenia
[e] Complexity Science Hub, Josefstädterstraße 39, A-1080 Vienna, Austria

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ABSTRACT

Cooperation plays an essential role in the evolution of social species, chief among all in humans. In this paper, we study the effects of compassion on the evolution of cooperation in spatial social dilemmas by introducing a payoff redistribution mechanism. In particular, a player whose payoff is larger than the average in its neighborhood will share some it with its comparatively poor neighbors. We find that such a simple redistribution mechanism, which we interpret as a form of compassion, significantly promotes the evolution of cooperation. While traditional network reciprocity already supports the formation of compact cooperative clusters, an in-depth analysis of payoff transfer events between players reveals an enhanced form of this phenomenon through the reinforcement of payoffs of co-operators that reside along the borders of such clusters. This significantly enhances the re-silience of cooperative clusters, who are in turn able to survive even at adverse conditions where traditional network reciprocity alone would long fail. We show that the observed positive effects of compassion on the evolution of cooperation are robust to changes of the interaction network and to changes in the type of the governing social dilemma.

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1. Introduction

Cooperation is ubiquitous in social and biological systems, yet how cooperative behavior emerges and sustains in a competitive world is a central problem in biology, social sciences and economics. Since the existence of cooperative behavior contradicts with Darwin's theory of evolution and natural selection [1–4], one would resort to game theory, a powerful theoretical framework for the study of evolution of cooperation, to come up with a sound explanation [5,6]. Prisoner's dilemma game (PDG), one of the simplest models in game theory, is a typical paradigm of explaining the cooperation emergence among selfish individuals [7–9]. In a typical prisoner's dilemma, two players simultaneously decide whether they wish to cooperate or defect. They will receive reward R if both cooperate, and punishment P if both defect. However, if one player defects and the other cooperates, the former gets temptation T as the latter gets the sucker's payoff S. The ranking of these four payoffs is $T > R > P > S$. It is clear that players tend to defect if they wish to maximize their own payoff, irrespective

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* Corresponding author.
** Corresponding author.
E-mail addresses: buaazhangjun@vip.sina.com (J. Zhang), matjaz.perc@uni-mb.si (M. Perc).

of the opponent's decision. In an unstructured population, where all individuals interact with each other, defectors have a higher average payoff than unconditional cooperators, resulting in a social dilemma of mutual defection. To overcome this unfortunate tragedy, the methods of promoting the cooperation has drawn much attention.

A pioneering work by Nowak and May demonstrates that the spatial structure can significantly affect the cooperative behavior by enabling cooperators to form clusters [10]. With this finding, a series of researches on different network structures were conducted, such as games on regular networks [11–13], complex networks [14–18], interconnected or interdependent networks [19–24], and dynamic networks [25,26]. Along this line of research, there are some natural mechanisms in the real world, including noise [27–31], reward and costly punishment [32,33], memory effects [34,35], inhomogeneous activity [37,38], variation in strategy transfer capability [36] and nonlinear neighbor selection [37–39], have been explored to explain cooperative behaviors.

However, in most previous literature, the widespread compassionate behavior, which is a common response of an individual to other suffering ones, is neglected. For example, Wilkinson presented the compassionate behavior among wild vampire bats during a 26−month study in northwestern Costa Rica [40]. The vampire bats share food by regurgitation of blood to the hungry populations. The compassionate behavior operates within groups containing both kin and those unrelated ones, and the experiments show that unrelated bats will reciprocally exchange blood in captivity. Compassionate behaviors exist in human society as well. Human devote money to philanthropy and create foundation to help the vulnerable groups. The compassionate behavior is part of the secret of the enormous success of human societies is our ability to cooperate with others and help less fortunate people. Very recently, several insightful works have highlighted the importance of the fraternity, friendliness, or other regarding preference, in resolving the social dilemma [41,42]. Continuing along this line of research, we are curious about the effect of compassionate behavior on the evolution of cooperation. For this purpose, a compassion mechanism is incorporated into the spatial game model, in which a player with high payoff will hand out a portion of its payoff to a distressed neighbor. Our work may shed some new light on evolutionary game dynamics.

In the remainder of this paper, we firstly introduce the spatial game model and the compassion mechanism. Subsequently, we investigate its effect on the evolution of cooperation in detail. In the last section, we summarize our conclusions.

2. Mathematical model

Simulations are carried out on a 100×100 square lattice with periodic boundary conditions. Initially, each player is designated either as a cooperator (*C*) or defector (*D*) with equal probability 0.5, who involves in the weak PDG [10] play with its von Neumann neighbors and gets payoffs according to the payoff matrix:

$$
\begin{array}{ccc}
 & C & D \\
C & R = 1 & S = 0 \\
D & T = b & P = 0
\end{array}
$$

The parameter $b \in (1, 2)$ characterizes the temptation of defectors. The evolutionary process is iterated forward in accordance with the following steps. Firstly, player *x* acquires its total payoff *Px* by playing the game with all its neighbors, which is defined as:

$$
P_x = \sum_{y \in \Lambda_x} \phi_x^T \psi \phi_y, \tag{1}
$$

where Λ_x denotes the neighbors of individual *x*. After each round, player *x* selects the poorest neighbor *y* among its neighbors, and compares its payoff with player *y*. If , the compassion mechanism works and the payoff will be redistributed as:

$$
F_x = P_x - p \cdot (P_x - P_y) \tag{2}
$$

$$
F_y = P_y + p \cdot (P_x - P_y) \tag{3}
$$

Here $p \in [0, 0.5]$ is the compassion parameter. When $p = 0$, the model is reduced to the original model; The upper bound of $p = 0.5$ ensures player *y* won't be richer than player *x* after the redistribution, reflecting the selfishness of individuals. For the convenience of discussion, we denote P_x as the payoff and F_x as the fitness of player *x*. Then all players select a neighbor *z* at random, and update their strategies with the Fermi updating rule based on the fitness of players:

$$
W_{x \to z} = \frac{1}{1 + exp[(F_x - F_z)/K]} \tag{4}
$$

where *K* characterizes the stochastic noise. Following common practices, here we set $K = 0.1$ [35,43].

In the following, the simulations are carried out on a 100×100 square lattice, whereby the final cooperation frequency is calculated over 10^3 generations after a transient time of 10^4 steps. Each data is averaged over 100 individual runs.