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Degree-based assignation of roles in ultimatum games on scale-free networks

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ABSTRACT

Most previous studies concerning ultimatum games in structured population assume either that the game roles are assigned randomly between linked individuals or that the game is played twice in an interaction, alternating the roles of proposer and responder. We develop a model in which individuals play the role of proposer with probabilities according to the degree. Specifically, players of two types are considered: (A) pragmatic agents, who do not distinguish between the different roles and aim to obtain the same benefit, and (B) agents whose aspiration levels and offers are independent. We investigate the evolution of altruistic behavior in pure populations with two different effective payoffs: accumulated payoffs and normalized payoffs. It is found that, for type B individuals, if the low-degree individuals can act as proposers with larger probabilities, the average value of offers reaches a higher point, irrespective of whether accumulated or normalized payoffs are used for strategy updating; for type A individuals, the two calculation methods for payoff lead to different outcomes.

1. Introduction

Cooperation is ubiquitous in the real world, ranging from biological systems to human economic society [1,2]. Understanding the origin of the flourishing cooperative behavior among selfish individuals remains one of the most exciting and fundamental challenges [3]. Evolutionary game theory, as a powerful mathematical framework, has been widely employed to elucidate this issue [4]. In particular, altruistic behavior, in which individuals perform costly acts for themselves to confer benefits to the rest of the population, has often been identified as a key mechanism for cooperation [5].

Since its introduction by Güth et al. [6], the ultimatum game has been regarded as a paradigmatic framework to study altruistic behavior, and it has aroused a lot of concerns of game theorists and experimental economists. The rules of a standard ultimatum game can be very easily summarized. Two players are told that they have to agree on how to split a sum of money. One of the players acts as proposer, who makes an offer on how to divide the money. If the other player (who acts as responder) accepts the proposer's offer, the deal goes ahead. If the responder rejects the offer, neither player gets anything. For a one-shot game played anonymously, the rational solution (also the Nash Equilibrium solution) is that the proposer would offer the least amount of money. And for the responder, the best strategy is to accept whatever is suggested, since "something is better than nothing". However, the overwhelming experimental evidence is at odds with the game-theoretic analysis. A lot of experimental results show that the rational solution is not what actually happens in

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the human real world. It was found that most proposers offer a fair share, with mean offers spanning the range from 25% to 57% of the amount to be divided. It is also observed frequently that unfair offers (typically below 20%) are rejected many times [7–10]. Interestingly, instances of fair behavior related to those arising on the ultimatum game have also been reported among non-human primates [11,12]. So why do individuals reject an unfair offer although they know such action will bring them zero benefit? Why can fairness evolve in a population of "selfish" and "rational" individuals?

There are many approaches for explaining the origin of these "irrational" behaviors. Repeated interactions, which act as haggling over a price, have been identified as a key factor in the evolution of fairness [13,14]. Nowak et al. developed a model in which a proposer can sometimes obtain information on what offers have been accepted by the responder in the past [15]. Thus, individuals who accept low offers run the risk of receiving reduced offers in the future. They showed that fairness will evolve with such a setting. Another possible scenario leading to large offers in the ultimatum game is the existence of empathy, where empathy means that individuals make offers which they themselves would be prepared to accept [16]. Costly punishment, which refers to an action that implies a fine for the punished person and that the punisher also pays a cost, has been identified as one possible route to promote altruistic behaviors among selfish individuals [17–20]. Indeed, rejections in ultimatum bargaining can be seen as a metaphor for exemplifying costly punishment, resulting in both sides getting nothing [21]. In Ref [22], the authors introduced a spatial ultimatum game with discrete strategies, and they showed that this simple alteration opens the gate to fascinatingly rich dynamical behavior.

It has been well accepted that population structure plays an important role in the evolution of altruistic behavior [23,24]. In the setting of the networks of contacts, individuals are situated on the vertices of a graph, and the edges indicate interactions among individuals. Page, Nowak, and Sigmund used evolutionary game theory to analyze the ultimatum game. They argued that natural selection suggests unfair outcomes in a non-spatial setting, but, in a spatial setting, much fairer outcomes evolve [25]. Furthermore, Kuperman and Gusman made a more detailed analysis of the effect of the topology on the spatial ultimatum game [26]. They have observed that both the increase of the neighborhood size and the increase of degree of disorder have a similar effect, leading a population of players towards responders with increasing levels of "rationality". Interestingly, fairness behaviors can still be established and sustained in a population consisting of zero-intelligence agents without any strategic reasoning and memory [27]. This is a vivid explanation for the observed fairness in both humans and non-humans. Additionally, culture [28–30], genetic, or biological features [31,32] have also been found to play important roles in the emergence of such altruistic behavior.

Herein we would like to point out that, to our knowledge, in most previous studies of ultimatum games on graphs, a common simplifying assumption is made, that an interaction of two linked individuals includes a couple of ultimatum games, alternating the roles of proposer and responder, or individuals are endowed with an equal opportunity to act the game roles (proposer or responder). Actually, there may be not such absolute equality in real social systems. What the population dynamics would be if the assignation of game roles is affected by other factors (e.g., wealth, social ties, or reputation) is still unclear. In this paper, we propose a simple model of the ultimatum game, in which a simple regime for assignation of the game roles is introduced. In the interaction between individuals, the ultimatum game roles are assigned based on the social connectivities of participators (i.e., they are degree based).

The rest of this paper is structured as follows. We give a brief introduction of our model in Section 2. Numerical results as well as discussions of these results are presented in Section 3. Concluding remarks are given in Section 4.

2. Model

The model consists of N individuals located on a static graph. Each vertex represents an individual, and each edge represents an interaction between the two linked individuals. Specifically, in an interaction, the ultimatum game is played only once, and the game roles are assigned to directly linked individuals according to their degrees.

The degree-based regime means that the probability with which an individual acts as proposer is proportional to the number of his/her social ties. For a specific ultimatum game between individuals i and j, the probability that i acts as the proposer is given by

$$\gamma_i = \frac{{k_i}^{\alpha}}{{k_i}^{\alpha} + {k_j}^{\alpha}}, \tag{1}$$

where k_i is the degree of i. The exponent α, which we define as the weight factor, uniquely measures to what extent the assignation of roles is related to degree. In other words, $\alpha = 0$ represents that all individuals, though with heterogeneous social ties, have the same opportunity to play the role of proposer. Highly connected individuals have more chances to play the role of proposer whenever α is positive; α being negative corresponds to the opposite situation.

In the simulations, we set the sum which is divided by the two game players equal to 1. Each individual, i, is assigned a strategy (p_i, q_i) represented by a pair of real numbers $(0 \le p_i, q_i \le 1)$. p_i denotes the amount offered to the other player if i is in the role of the proposer, while q_i denotes the minimum acceptance level when i acts as the responder. Thus, when individual i with strategy (p_i, q_i) interacts with individual j with strategy (p_j, q_j), the payoff w_{ij} individual i will get is

$$w_{ij} = \begin{cases} 1 - p_i & \text{if } i \text{ acts as proposer and } p_i \ge q_j \\ 0 & \text{if } i \text{ acts as proposer and } p_i < q_j \\ p_j & \text{if } j \text{ acts as proposer and } p_j \ge q_i \\ 0 & \text{if } j \text{ acts as proposer and } p_j < q_i. \end{cases}$$