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The extended reciprocity: Strong belief outperforms persistence

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ABSTRACT

The existence of cooperation is a mysterious phenomenon and demands explanation, and direct reciprocity is one key potential explanation for the evolution of cooperation. Direct reciprocity allows cooperation to evolve for cooperators who switch their behavior on the basis of information about the opponent's behavior. Here, relevant to direct reciprocity is information deficiency. When the opponent's last move is unknown, how should players behave? One possibility is to choose cooperation with some default probability without using any further information. In fact, our previous paper (Kurokawa, 2016a) examined this strategy. However, there might be beneficial information other than the opponent's last move. A subsequent study of ours (Kurokawa, 2017) examined the strategy which uses the own last move when the opponent's last move is unknown, and revealed that referring to the own move and trying to imitate it when information is absent is beneficial. Is there any other beneficial information else? How about strong belief (i.e., have infinite memory and believe that the opponent's behavior is unchanged)? Here, we examine the evolution of strategies with strong belief. Analyzing the repeated prisoner's dilemma game and using evolutionarily stable strategy (ESS) analysis against an invasion by unconditional defectors, we find the strategy with strong belief is more likely to evolve than the strategy which does not use information other than the opponent player's last move and more likely to evolve than the strategy which uses not only the opponent player's last move but also the own last move. Strong belief produces the extended reciprocity and facilitates the evolution of cooperation. Additionally, we consider the two strategies game between strategies with strong belief and any strategy, and we consider the four strategies game in which unconditional cooperators, unconditional defectors, pessimistic reciprocators with strong belief, and optimistic reciprocators with strong belief are present.

1. Introduction

We observe cooperation in a broad range of organisms. However, cooperation is costly, and the existence of cooperation can be regarded as a mysterious phenomenon (Hamilton, 1964; Trivers, 1971; Nowak, 2006, 2012). It has been argued that the establishment of cooperation is possible if cooperators imitate the opponent's behavior in the past when encountering the same opponent repeatedly, which is called direct reciprocity (Trivers, 1971; Axelrod and Hamilton 1981; Axelrod, 1984; Dugatkin, 2002; Fischer, 1988; Hart and Hart, 1992; Packer, 1977; Wilkinson, 1984, 1988).

However, animals have cognitive capacity limitations (Larose and Dubois, 2011; Stevens and Hauser, 2004; Stevens et al., 2005; Axelrod and Dion, 1988; McElreath and Boyd, 2007; Boerlijst et al., 1997; Kollock, 1993; Miller, 1996; Nowak et al., 1995; Brandt and Sigmund, 2006; Bowles and Gintis, 2011; Panchanathan and Boyd, 2003, 2004; Kurokawa, 2016a, 2016b, 2016d, 2016e, 2017; Kurokawa and Ihara, 2017). And a possible problematic case relevant to the theory of the evolution of direct reciprocity arises when they have cognitive capacity limitations.

In order to deal with this problem, theoretical previous studies considered the case where perception errors in which the opponent player mistakenly regards the focal player's cooperation as defection (McElreath and Boyd, 2007 page 142; Sigmund, 2010 page 75) or the opposite case (Sigmund, 2010 page 75). In either way, in these settings, a player always recognizes that the opponent player cooperated or defected.

However, it may be reasonable to consider the situation where players do not receive wrong information but receive no information itself. In this case, the following question is raised: When facing the situation where players do not get information about what the opponent did, how do players behave? It is considered that there are multiple strategies. Our previous paper (Kurokawa, 2016a) considered the strategy which cooperates with some constant default probability without using further information when the information about the opponent's last behavior is absent.

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Our previous paper (Kurokawa, 2016a) examined the case where there are two strategies: direct reciprocators and unconditional defectors. And by using evolutionarily stable strategy (ESS) analysis (Maynard Smith, 1982; Hofbauer and Sigmund, 1998), our previous paper (Kurokawa, 2016a) specified the stability condition for direct reciprocators and additionally showed that optimism (i.e., the frequency of players' cooperating with the opponent when information about the opponent's behavior is unavailable) does not make impact on the evolution of cooperation.

Thus, Kurokawa (2016a) considered the strategy which relies only on the information about the opponent player's last move. However, even in the case where information about the opponent's behavior is not accessible, there may be other beneficial information.

One possibility for the beneficial information is information about the own last move. For example, a recent experimental study (Gutiérrez-Roig et al., 2014) reported that humans tend to cooperate with a higher probability when the focal player cooperated in the last move than when the focal player defected in the last move, and Kurokawa (2017) presumed that referring not only to the opponent player's previous move but also to the own previous move can be regarded as an alternative nice choice. And then Kurokawa (2017) revealed that the strategy which uses tit-for-tat when the opponent player's previous move is known; otherwise the strategy repeats the own move of the previous round (which is interpreted as being persistent) outperforms the strategy which cooperates with some default probability without using the own previous behavior conceived in Kurokawa (2016a). Referring to the own behavior and imitating to it is beneficial for its evolution (Kurokawa, 2017).

Thus, it has been found that there is beneficial information other than the co-player's last move, and another possibility for the beneficial information is information about the opponent player's move in the past, which is not limited to the "last" move. And having strong belief (i.e., believing that the opponent's behavior is unchanged) may be a nice option as well. The reason why we consider so is that it is considered that if players have strong belief, cooperating in a round elicits cooperation from the co-player not only in the next round but also in the subsequent rounds. In this paper, we consider the repeated interaction by the same opponent and examine the likelihood of the evolution of cooperation in the case where strategies have strong belief.

The paper is organized as: the models are described in Section 2; in Section 3, we introduce two previous works: one previous work dealt with the case where players cooperate with some constant probability (Kurokawa, 2016a) and the other previous work dealt with the case where players refer to the own behavior and imitate it when the information about the opponent is absent (Kurokawa, 2017); in Section 4, we examine the case where players believe that the opponent's behavior is unchanged when the information about the opponent's behavior is absent, and examine how strong belief affects the evolution of reciprocity; and in Section 5, we summarize the results and suggest some future works to be undertaken.

2. Model

Individuals interact with individuals at random. Consider the iterated prisoner's dilemma game where individuals choose to either cooperate or defect in each round. A cooperator pays an opponent a benefit b at a personal cost c, where $b > c > 0$, while defectors do nothing. In each interaction, any given pair continues on to play the prisoner's dilemma with probability δ, where $0 < \delta < 1$, while their relationship terminates with probability $1-\delta$. Here, we consider the case where information is imperfect. We use e, where $0 < e < 1$, to denote the probability that information is somehow blocked, i.e., a player cannot get access to information about an opponent's behavior. We assume that players always know their own behaviors while players do not always know their opponent's behaviors.

It is considered that animals are error-prone (May, 1987; McElreath and Boyd, 2007; Sigmund, 2010; Kurokawa, 2016c). We use μ, where $0 < \mu < 1$, to denote the error rate that an individual who intends to cooperate fails to do so and finally defects.

Our previous study (Kurokawa, 2016e) considered the following strategy space. The space of memory-one strategies for a game between two players for the current case (where the action of the opponent can be unknown) would be a vector of four probabilities: f, P_C, P_D, and P_U, where f is the probability of trying to cooperate in the first move, P_i is the probability that a focal individual tries to cooperate in this round when the opponent adopted i in the last round (where C stands for "cooperate," D stands for "defect," and U stands for "unknown," corresponding to the case where the information of the opponent's behavior is not available). $0 \le f, P_i \le 1$ is satisfied since f and P_i are probabilities. This formulation is a natural extension of the previous studies (see e.g., Sigmund (2010)), which deal with the case where the information about the opponent is always accessible. We deal with R_a ((f, P_C, P_D, P_U)=(1, 1, 0, a), where $0 \le a \le 1$) in Section 3.1.

The strategy proposed in the previous paragraph does not refer to the own behavior in the previous round. As a natural extension of this strategy, our previous study (Kurokawa, 2017) considered the strategy which refers to the own behavior and decides actions based on it. The space of memory-one strategies for a game between two players for the current case would be a vector of seven probabilities: f, $P_{C,C}$, $P_{C,D}$, $P_{D,C}$, $P_{D,D}$, $P_{C,U}$, and $P_{D,U}$, where $P_{j,\ k}$ is the probability that a focal individual tries to cooperate in this round when the focal player adopted j in the last round and the opponent adopted k in the last round. $0 \le P_{j,k} \le 1$ is satisfied since $P_{j,\ k}$ are probabilities. We deal with PTFT (persistent tit-for-tat) ((f, P_{CC}, P_{CD}, P_{DC}, P_{DD}, P_{CU}, P_{DU})=(1, 1, 0, 1, 0, 1, 0)) in Section 3.2.

The strategies we mentioned in the previous two paragraphs are conceived in our previous studies (Kurokawa, 2016e, 2017), and they are memory-one strategies. This paragraph introduces the strategy newly conceived in this paper. Let us consider the reciprocal strategy which has infinite memory, and has strong belief (i.e., believes that the opponent's behavior is unchanged) (SB_d). SB_d tries to cooperate with probability 1 in the first round. In the following rounds, SB_d refers to the latest available information about the opponent's behavior (and believes that the opponent's behavior is unchanged) and SB_d tries to cooperate with probability 1 when the latest available information about the opponent's behavior is cooperation, while SB_d defects with probability 1 when the latest available information about the opponent's behavior is defection. In the case where no information about the opponent's behavior throughout the previous rounds is present, SB_d tries to cooperate with probability d, where $0 \le d \le 1$. The parameter (d) can be regarded as an index of "optimism". We deal with this strategy in Section 4.

3. Previous studies

3.1. Previous studies (Kurokawa, 2016a)

Let us briefly review the results of our previous analysis (Kurokawa, 2016a). Kurokawa (2016a) explored the competition between two particular strategies: R_a and unconditional defection (ALLD) ($f=0$ and $P_i=0$ for every i). In this case, R_a can be considered to be tit-for-tat, which has various levels of optimism (a). Kurokawa (2016a) derived the condition under which a strategy R_a