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Does information of how good or bad your neighbors are enhance cooperation in spatial Prisoner's games?

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ABSTRACT

Network reciprocity is one of the key mechanisms to solve social dilemmas, and has attracted many researchers for the last decade. Here, we explore what happens if network reciprocity is dovetailed with indirect reciprocity. This is motivated by the idea that a player may utilize observed information to evaluate his neighbors. Simulations based on our minimal model reveal that adding indirect reciprocity does not always increase the level of cooperation beyond the level of model without indirect reciprocity. This implies that the combination of two different reciprocity mechanisms, each enhancing cooperation if applied independently, can lead negative interference effect on cooperation. The details of this depend on type of action assessment system determining what is good and bad. Interestingly, we found that a high level of information is not always superior to low levels of information.

1. Introduction

How altruistic behavior can emerge, and it can be sustainable among many animal species have attracted many researchers including biologists and statistical physicists (e.g. [1]), because paying cost for cooperation to help others is at odd with natural selection. Evolutionary game theory (EGT) with huge amount of computational and experimental efforts has provided an array of possible answers to this challenging question. One set of those explanations involves assortment caused by spatially structured population, which is called network reciprocity. Although EGT premises either 2-players and 2-strategy games (2×2 games) or multi-players and 2-strategy games without losing its generality, prisoner's dilemma (PD), one of the four classes in 2×2 games, has been preferably presumed as a good metaphor for social dilemma situation.

Network reciprocity goes back to pioneer work by Nowak & May [2] on the spatial prisoner's dilemma (SPD) game. Since then, the network reciprocity has attracted a lot of interest, by both theoretically and numerically (e.g., [3–13]), but also by experimentally (e.g., [14–17]). Although the central assumption of the model, namely, "playing with the neighbors and copying successful strategies from them," is simple, the associated models show that even agents which are unsophisticated in terms of information processing can develop cooperative social systems. But one question that could be raised is whether more intelligent agents, such as humans, really rely on such a simple mechanism. It seems plausible that one would react differently to each of neighbors, depending on this particular neighbor's cooperative tendency instead of just uniformly either cooperating (C) or defecting (D) with all neighbors, as most of the previous SPD models assume. An intelligent agent can use information derived from the observation on what happened in the previous time around him in order to draw an appropriate assessment on whether or not his neighbors act cooperatively. Information allows to react in more sophisticated and more complex manner, and may eventually lead to a higher payoff. In this way, a more clever way of information use could evolve.

The term "information" contains several layers. Anything helping an agent to discriminate someone from others can be viewed as "information". In this sense, what is called tag recognition provides information (e.g., [18,19]). But a tag is constant or does not change frequently in an agent's lifetime. Although tag systems can help an agent to evaluate his similarity to his opponents, it is only of temporary use, since tags can be expected to lead to continuous adaptation [20,21]. Contrasting to this, a mechanism providing time variable information that can indicates the cooperative tendency of a co-player could foster emerging cooperation. This would be a mechanism of indirect reciprocity. Indirect reciprocity can be intuitively understood from the phrase "I will help you if you have helped someone" [22]. There have been many brilliant studies on indirect reciprocity (e.g., [22–30]). Those models are based on two ingredients: The first one is *reputation* which indicates whether one's game opponent is good (hereafter, G) or bad (hereafter, B) –

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or, alternatively, a finer assessment of players. The second one is a *norm* which defines what is good or bad based on what happened in the past. Thus, the norm is a rule to assess one's reputation. Apart from a few exceptions (e.g., [31,32]), a single norm is shared with the whole population in these models, otherwise emerging cooperation becomes very fragile [32]. A norm determines whether a certain agent is good or bad, based on his action to his game opponent and this opponent's reputation. Additionally, in some cases (e.g., [29,30]), the focal agent's reputation; either G or B, is also taken into account. The number of norm variations is $(2^2)^2 = 16$ for the former case, while $((2^2)^2)^2 = 256$ for the latter case.

What would be observed if two different mechanisms fostering the evolution of cooperation are combined into a single model? Since there are two mechanisms, does this enhance cooperation even more? Or, because of a certain negative interference effect, does it rather deteriorate what each single mechanism can bring? There have been several precursors who assumed network reciprocity combining with one of other reciprocity systems such as direct reciprocity. For example, Ref. [33] reported that a more cooperation can be established by additionally presuming direct reciprocity in a SPD game, where an agent in a spatially structured system is allowed to have memory and a strategy to distinguish each of his neighbors when he cooperates or defects. On the other hand, combining a tag recognition model with a structured population has shown that how high and low assortment of a population affect the tag recognition mechanism in very different ways, sometimes even effectively decreasing cooperation [21]. Ref. [2] clarifies that combining tag model with network reciprocity does not lead to positive but rather to negative interference in terms of cooperation.

However, the question what would happen if an agent who is playing SPD games is given information based on an indirect reciprocity mechanism is still open. Thus, the present study seeks an answer of whether or not adding indirect reciprocity to network reciprocity can foster cooperation. Although one may think that this should certainly increase cooperation comapred to conventional SPD games, giving more information could also devastate network reciprocity. The current study intends to address this particular question by building a minimal model dovetailing network reciprocity with indirect reciprocity.

2. Model setup

First, we assume a simple network reciprocity model as the default case where synchronous Imitation Max (hereafter IM; that is same as Best-takes-over [34]) as agent's strategy updating rule is assumed. As population structure, we assume a 2D lattice with degree of 8 ($k = 8$), i.e. a Moore neighborhood. This is a very popular deterministic update rules (summarized e.g. in, [11,13]), where an agent imitates the neighboring strategy which lead to the highest payoff agent among both his own neighbors and himself. Since we aim for a minimal model, no stochastic elements, which arise e.g. through asynchronous updating, stochastic updating rules, or heterogeneous networks, are taken into account. This is because introduction of such stochastic elements inevitably makes it more difficult to draw a conclusion on the question above-mentioned.

In the default setting, we focus on two cases. One assumes a discrete strategy system, where an agent has a binary strategy; either C or D. A second case assumes a mixed strategy system, where an agent uses a real number between 0 (D) and 1 (C) as his strategy, but the action is still restricted to either C or D, thereby his action is probabilistically determined by his strategy.

In our model, a focal agent; i is able to obtain his neighbor js' information; Obs_j that is a binary *evaluation* about j; either good (G) or (B). On the other hand, each agent has a *strategy*, defined by Str, which evolves in time according to synchronous IM. The action of agent i towards his neighbor j is defined as

$$\text{If } Obs_j \geq Str_i \text{ Agent } i \text{ cooperates with Agent } j; \text{ otherwise defects.} \quad (1)$$

The evaluation of each agent; Obs is defined by *action assessment*. An important difference from previous indirect reciprocity models [22–30,35,36], where a social norm determines an agent's reputation, is that the action assessment only refers to the actions of the opponent player in the previous time step, but not on the assessment of the focal and opponent players. We assume three types of action assessment rules

(a) **Action scoring (hereafter; AS):** If an agent cooperates, his action is evaluated as good (G). If he defects, he is labeled with bad (B).
(b) **Action judging (hereafter; AJ):** If an agent only cooperates to a cooperator or defects to a defector, his action is evaluated as G. Otherwise, the action is evaluated as B
(c) **Discourage exploitation (hereafter; DE):** An agent's action is given G as long as he is not exploiting his neighbor, i.e. as long as he does not defect against a cooperator.

Table 1
How each of the three action assessments gives either good (G) or bad (B) for mutual cooperation (R), mutual defection (P), Sucker (S) and Temptation (T) in a 2×2 game.

(i) Action scoring; AS			
		Opponent	
		Cooperation	Defection
Focal player	Cooperation	G	G
	Defection	B	B
(ii) Action judging; AJ			
		Opponent	
		Cooperation	Defection
Focal player	Cooperation	G	B
	Defection	B	G
(iii) Discourage exploitation; DE			
		Opponent	
		Cooperation	Defection
Focal player	Cooperation	G	G
	Defection	B	G

Table 1 summarizes how each of the three action assessments is evaluated; leading to either G or B in a two-player and two-strategy (2×2) game.

Note that AS only sees how a player behaves, i.e. whether he cooperates or defects, irrespective to his opponent's action. In this point AS shares the basic concept with what-is-called *Scoring*, one of the social norms [26,27], assessing those who give (refuse) to help for good (bad) opponent, and with TFT (Tit-for-Tat), one of the direct reciprocity strategies [37], cooperating to a cooperator and defecting to a defector.

AJ encourages equal actions; obtaining R or P. The concept of AJ seems analogous to *Stern-judging*, which regards a defection for a bad opponent as good unlike Scoring [28]; and qualitatively similar to Win-stay & Lose-shift [38], which is another direct reciprocity strategy, cooperating after mutual defection as well as mutual cooperation and defecting after being exploited as well as exploiting.

DE is partially analogous to Simple-standing, which assigns good reputation as long as a player not exploiting a good-labelled opponent [23,35,36].

With respect to the information actually given to each agent (meaning observed data for each agent); Obs, we proceed on the following way:If the number of Agent i's actions to his neighbors that are evaluated as good in the previous time step is less (more)