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Memory boosts turn taking in evolutionary dilemma games

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ABSTRACT

Spontaneous turn taking phenomenon can be observed in many self-organized systems, and the mechanism is unclear. This paper tries to model it by evolutionary dilemma games with memory mechanism. Prisoner's dilemma, Snowdrift (including Leader and Hero) and Stag-hunt games are unified on an extended S–T plane. Agents play game with all the others and make decision by the last game histories. The experiments find that when agents remember last 2-step histories or more, a kind of cooperative turn taking (CAD) bursts at the area of Snowdrift game with restriction of $S+T>2R$ and $S \neq T$, while the consistent strategy (DorC) gathers on the line of $S+T>2R$ and $S=T$. We also find that the system's fitness ratio greatly improved with 2-step memory.

1. Introduction

Spontaneous turn taking can be seen as an action of rotation or oscillation in populations (Jiang et al., 2006). This phenomenon has been found in many different systems such as the density oscillator (Steinbock et al., 1998), ticking hour glass (Wu et al., 1993), RNA Polymerase traffic on DNA (Sneppen et al., 2005) and traffic of ants (Dussutour et al., 2005). Turn taking can also solve the problem of pedestrians passing a bottleneck (Burstedde et al., 2001; Helbing and Molnár, 1995; Helbing et al., 2000, 2005).

In this paper we introduced evolutionary game theory to model the action of turn taking in self-organized populations (Gintis, 2000; Hofbauer and Sigmund, 1998; Maynard Smith, 1982; Nowak, 2006a). It may also be able to illustrate the systems mentioned above. Evolutionary game theory (EGT) is the application of game theory to evolving populations of life forms in biology. EGT is useful in this context by defining a framework of contests, strategies, and analytics into which Darwinian competition can be modeled (Maynard-Smith and Price, 1973).

The payoff matrix of a 2-people-2-strategy game is shown in Table 1. There are three kinds of relationships between the players: player cooperates with each other and gets payoff R (R reciprocity); player defects with each other gets payoff P (P reciprocity); player cooperates with defector gets S and the opponent gets T (ST reciprocity). There exists social metaphor for dilemma situations (Rand and Nowak, 2013) such as Prisoner's dilemma game (PD, $T>R$, $P>S$), Snowdrift game (SD, $T>R$, $S>P$), Stag hunt game (SH, $R>T$, $P>S$).

In Hawk dove game (also named as snowdrift game, $T>R$, $S>P$) (Maynard-Smith and Price, 1973), when facing a new territory, if one player choose cooperation (dove strategy, to avoid combat and may lose the territory), the best strategy for the other is defection (hawk strategy, to combat in any case and may acquire the territory), and vice versa. However, the cooperator usually get lower payoff than the defector which will injure the cooperator's enthusiasm if the game is played repeatedly. Is there any way to help the 2 player to reach a state of "turn taking" in ST reciprocity: the one who cooperate will defect next time; and the one who defect will cooperate next time, and going on?

Some studies revealed the relationship between turn taking and evolutionary games. There are some dilemma games that related to turn taking, including leader game, Hero game and common-pool resources game (Browning and Colman, 2004; Lau and Mui, 2012; Rapoport, 1967). These games all belong to the subtype of Snowdrift game, and the game matrix meets the conditions of $T+S>2R$.

Crowley et al. (1998) found turn taking phenomenon in evolutionary games. They studied iterated complementarity dilemma game, and observed two special cooperation mechanism: cooperation alternating with defection (CAD), which means that both players taking alternative strategies: (cooperate, defect), (defect, cooperate), ...; the other is defection or cooperation (DorC),

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Table 1
Payoff matrix for a 2 × 2 game.

		Opponent	
		Cooperation (C)	Defection (D)
Ego	Cooperation (C)	R	S
	Defection (D)	T	P

which means that both players taking one strategy and do not change: (cooperate, defect), (cooperate, defect), ... These two mechanisms both belong to ST reciprocity and CAD is a kind of turn taking. We call CAD as cooperative turn taking for it can help agents overcome the dilemma of games like Snowdrift.

Browning and Colman (Browning and Colman, 2004; Colman and Browning, 2009b) studied iterated Prisoner's dilemma, Snowdrift game, Hero game and Leader game. They made agents remember the last 3-step histories and adopt genetic algorithm as strategy evolutionary rule, and they also observed turn taking strategies like CAD.

Tanimoto and Sagara (2007) defined a special 2-dimensional Dg–Dr game plane, which including Prisoner's dilemma, Snowdrift, Stag Hunt, Leader and Hero (Fig 1(b)). Wakiyama and Tanimoto (2011) studied the system when agents gamed and updated strategies in different groups on Dg–Dr plane. Agents had one-step memory and CAD strategy was found in the area of harmony game.

An important application of EGT is in the researches of cooperation mechanism (Axelrod and Hamilton, 1981; Nowak, 2006b). Cooperation is the process of groups of organisms working or acting together for their common benefit, as opposed to working in competition for selfish benefit (Kohn, 1992). Since Nowak found that cooperation can exist in evolutionary Prisoner's dilemma on lattice. In 1992 (Nowak and Robert, 1992), many scientists were interested in the issue of how cooperation exist in rational individuals (Hauert and Szabo, 2005; Nowak et al., 2010; Perc and Szolnoki, 2010; Roca et al., 2009; Szabó and Fáth, 2007).

In the study of turn taking in evolutionary game, memory is an important mechanism. The origin of the study should start from Axelrod's tournaments in 1980s (Axelrod, 1984, 1987; Axelrod and Hamilton, 1981). He conducted computer tournaments to find the strategy that performs best in a population playing PD game. TFT (Tit-for-tat) won both of the tournaments. However, Nowak found that WSLS (win-stay, lose-shift) outperforms TFT in 1993 (Nowak and Sigmund, 1993). Both TFT and WSLS are based on memory. There are many studies about memory mechanism and strategies (Alonso-Sanz, 2009; Alonso-Sanz and Martin, 2006; Deng et al., 2010; Imhof et al., 2007; Liu et al., 2010; Posch, 1999; Qin et al., 2008; Tanimoto and Sagara, 2007; Wang et al., 2006).

ST reciprocity is a subtype of cooperation. People usually think that bilateral cooperation is the key to overcome the dilemma of 2-person game. However, in the studies of Chen et al. (2013) and Wang et al. (2014), the system's cooperation ratio is composed by R

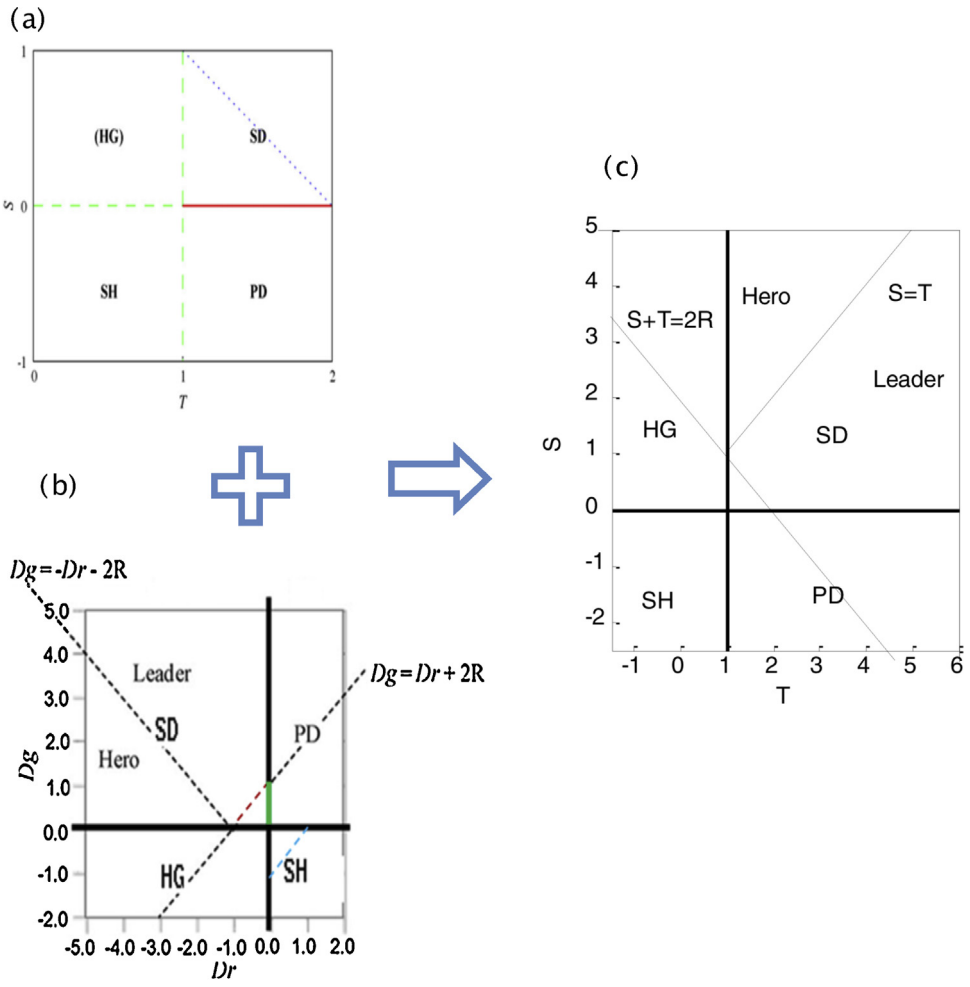

Fig. 1. Extended S–T plane. (a) general S–T plane; (b) Dg–Dr plane defined by Tanimoto; (c) unified extended S–T plane. PD is Prisoner's dilemma game, SD is Snowdrift game, SH is Stag hunt game and HG is Harmony game (without dilemma). In (b) and (c), PD game includes area of S + T > 2R, which is not the common definition, we call it extend PD game.