Enhanced Cooperation in the N-person Iterated Snowdrift Game Through Tag Mediation

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***Abstract*— This paper investigates whether tags can elevate cooperation levels in N-player iterated evolutionary snowdrift games. Tags give agents the ability to form groups that can prosper under certain circumstances. Previous work showed tags promote cooperation in iterated prisoner's dilemma games but no work has seen if they enhance cooperation in snowdrift games. We studied different tag models used in prisoner dilemma games and found they also promote cooperation in snowdrift games. We also discuss the relationship between tags and the red queen effect.**

I. Introduction

Cooperation is ubiquitous throughout nature. Numerous examples exist throughout the plant and animal kingdoms, but the underlying mechanisms remain allusive. Agents may choose to cooperate or defect with other agents but defection often pays higher dividends when others cooperate. No one benefits though if everyone defects. This conflict is referred to as a social dilemma [1].

Game theory offers a framework to study cooperation and the conditions under which it develops. The bulk of prior social dilemma research has heavily focused on the *prisoner's dilemma* (PD). In PD two agents decide whether to cooperate (*C*) or defect (*D*) and the payoffs to each agent depends on the choice of the other agent. If one chooses *C* while the other chooses *D*, then the cooperator receives a sucker cost $S = -c$ while the defector gets a temptation payoff $T = b$ (with $b > c > 0$). Two cooperative agents get a reward payoff $R = b - c$; two defecting agents get a punishment payoff $P = 0$. There are two payoff constraints: $T > R > P > S$ and $2R > T + S$.

Defection always pays the most if agents compete only one time (so-called "one shot" games). However, in iterated games, such as the iterated prisoner's dilemma (IPD), agents meet multiple times and past encounters influence the future choices agents make. This is called *reciprocity* and there are two types. In direct reciprocity agent *x* remembers past encounters with agent *y* and picks *C* or *D* accordingly the next time they meet. In indirect reciprocity *x* and *y* may not have previously met. But *y* has acquired a reputation from prior play with other agents; *x* uses that information to decide how to play against *y* if they do meet. Studies indicate reciprocity can promote higher cooperation levels in a population under certain circumstances [2], [3].

Another interesting game that has attracted much recent interest is the *snowdrift* (SD) game[1]. In the one shot SD game the best strategy is defection if the other agent cooperates, but worse if the other agent defects [4]. The SD game has a reordering of the payoffs used in PD—i.e., $T > R > S > P$. The *iterated snowdrift* (ISD) game, like IPD, has repeated encounters. In the N-player ISD version the best strategy is to defect if the majority cooperates and to cooperate if the majority defects. Thus some fraction of cooperators will always survive unlike IPD where the all-D case is the only stable equilibrium. N-player ISD qualifies as a social dilemma [1].

One complaint with IPD is it predicts lower cooperation levels than what was observed in human experiments. ISD, on the other hand, predicts much higher human cooperation levels [5], which explains why ISD is attracting so much recent interest.

Numerous N-player ISD investigations have been conducted over the past decade. Some work studied well-mixed populations [6] where in each round an agent can play any other agent with some positive probability. However, a large number of interactions seldom occur in the real world—especially in very large populations. The more typical situation is agents regularly interact with only a small fraction of the population due to geographical or social limitations. Some IPD and ISD studies rely of spatial graphs where only limited interactions are allowed. Each agent is assigned a node in the graph and only interactions with agents on adjacent nodes is permitted. For example, if agents are placed on nodes in a 2-D lattice with periodic boundary conditions, then interactions are only allowed with their north, south, east and west neighbors. ISD work with spatial graphs includes 2-D lattices [7], random networks [8], small-world networks [9] and scale-free networks [10].

Over the past 10–15 years research on *tag mediated* interactions has appeared. In tag mediated games each agent has a "tag" (label, marker or other distinctive feature). Agents prefer competing against other agents with similar tags. The first work on tags we are aware of is by Hamilton [11]. He envisioned an allele that caused an individual to produce some trait recognizable by others in the same species. This trait led to preferential selection.

Tags provide a richer environment for studying cooperation in very large populations. Spatial structures—even scale-free networks—are too rigid because interactions are limited to nearest neighbors defined by a fixed graph structure. Tags provide two advantages, which makes them more accurate models of social relationships. First, tags naturally parti-

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[1]SD is also known as the Hawk-Dove game or the Chicken game.

tion the population into groups where group members have similar tags. Groups of any desired size can be created by carefully choosing the initial tag assignments. Second, agents can easily migrate to other groups where they might receive higher payoffs by changing tags. Group viability is measured by individual fitness with respect to the entire population. Hence, tags allow beneficial relationships to flourish and detrimental ones to dissolve.

Several researchers have looked at tag mediated IPD games, but after an extensive literature search we could not find any papers on tag mediated ISD games. Prior IPD work used three types of tags: (1) binary strings, (2) real numbers and (3) multiple integers. In this paper we present experimental results conducted on an ISD game with different tag types. Our results indicate tags can significantly improve cooperation levels in large population ISD games.

The paper is organized as follows. Section II formally defines the SD game and briefly describes the three tag types. Section III gives detailed information on our experiments. An in-depth analysis is provided in Section IV. Finally in Section V we summarize our results and describe future research efforts on tag mediated games.

II. Background

A. The Snowdrift Game

Picture two drivers who are stuck on opposite sides of a snowdrift. The only way they can get free is to shovel the snow to remove the snowdrift. Cooperation means a driver agrees to get out of his car and shovel snow. Defection means a driver stays inside his car and hopes the other driver gets out and starts shoveling snow. Cooperation pays a benefit $b > 0$ (freeing the car) but the effort of shoveling snow has a cost $c < b$. If both drivers cooperate this cost is shared equally. A defector always does better when the other driver cooperators—he still gets the payoff b but without paying any cost c. But a dilemma exists because if both defect than neither one gets any benefit. The SD payoff matrix is

$$\begin{array}{r} \\ \text{Payoff to } C \\ \text{Payoff to } D \end{array} \begin{array}{c} \begin{array}{cc} C & D \end{array} \\ \begin{pmatrix} b - \frac{c}{2} & b - c \\ b & 0 \end{pmatrix} \end{array} \tag{1}$$

In terms of T, R, S and P the ISD payoff matrix is

$$\begin{array}{r} \\ \text{Payoff to } C \\ \text{Payoff to } D \end{array} \begin{array}{c} \begin{array}{cc} C & D \end{array} \\ \begin{pmatrix} \text{R} & \text{S} \\ \text{T} & \text{P} \end{pmatrix} \end{array} \tag{2}$$

where $T = b, R = b - \frac{c}{2}, S = b - c$ and $P = 0$. This ISD payoff matrix is identical to the one traditionally shown for IPD. However, ISD uses different values for T, R, S and P to get the required ISD ordering $T > R > S > P$.

B. Tag Variants

This section describes 3 different tag types that were previously employed. These tag types were only previously used to study cooperation in IPD games.

- T1 Tags (*real number genes*)

This tag was used by Riolo [12]. Players have 5 genes $(i, p, q, \mathcal{T}, b)$. The first 3 genes, called strategy genes, are probabilities. For a player x, i_x is the probability x initially cooperates; p_x is the probability of cooperation in move m if the opponent cooperated in move $m-1$; q_x is the probability of cooperation in move m if the opponent defected in move $m - 1$. Opponents are randomly chosen and players accumulate payoffs acquired during a round of play.

A player and his randomly chosen opponent may not necessarily play at all; they must both agree to play. The tag gene $\mathcal{T} \in [0, 1]$ determines if play occurs while the tag bias $b \in (0, 100]$ determines how close the tag gene values must be if the game is to be played. Suppose player x randomly chooses player y. The tag dissimilarity is defined as

$$d_{x,y} = |\mathcal{T}_x - \mathcal{T}_y| \tag{3}$$

x agrees to play y with probability $1 - d^b_{x,y}$. Low b values (≤ 1) means the players' tag values must be nearly equal for play to occur while larger values mean tag values can be significantly different and play can still occur. If x agrees to play y, then y conducts the same test (possibly with a different b value). Both players must agree before play occurs. If either acceptance test fails x picks another opponent. After 5 unsuccessful attempts a randomly opponent is chosen and the two are forced to play. The game is played 4 times and players accumulate payoffs. Average payoff determines fitness.

Mutation is performed by adding a small standard deviation, Normally distributed random variable to the genes. The tag gene ($\mathcal{T}$) mutation is circular in the sense that adding +0.2 to a current value of +0.9 results in a new value of 0.1. This circular scheme is not used for the strategy genes since this could change a strong cooperator into a strong defector.

- T2 Tags (*multiple integer tags*)

This tag model was described by Howley and O'Riordan [13]. It is similar to the T2 tag (players have i, p and q genes) except the tag gene is now an integer $\{1\ 2 \cdots L\}$ where L is the maximum number of tags. The primary difference, however, is players can have multiple tags. Opponents are randomly chosen. Two players must have matching tags to compete, but they need have only one tag value in common. That is, if IS_x denotes the integer tag set for player x, then x plays y if $IS_x \cap IS_y \neq \emptyset$. This feature allows players to compete in multiple groups, which might improve their survival chances. Note $|IS_x| = |IS_y|$ is not required.

Mutation of the 3 strategy genes is done as before. Tags are mutated by picking a different integer from $\{1\ 2 \cdots L\}$ with some small probability.

- T3 Tags (*binary strings*)

This particular tag was initially used by Hales [14]. Each play has a $\ell + 1$-bit binary string. The first bit is a strategy bit ('0' for always cooperate; '1' for always defect) while the remaining ℓ bits are the tag. All players with matching tags are assigned to a group. Singletons are players with tags that don't match any other player's tag.

During each round each player randomly picks an opponent. If no opponent with a matching tag is found after a fixed number of tries, one more opponent is randomly chosen and the two are forced to play. Payoffs are awarded to both players. Every player plays at least one game per round but some may play more games because other players picked them for opponents. Fitness equals the average payoff per round.

Mutation by bit flipping is applied to the strategy bit or the tag bits with probability μ_S and μ_T, respectively. Flipping the strategy bit changes the strategy. Flipping tag bits allows the player to switch to a different group.

McDonald and Sen conducted an investigation along similar lines [15]. They used a real number tag $t \in [0,1]$ and then subdivided the unit interval into 2^ℓ bins. Every real number is thus assigned to a specific bin. Two agents have identical tags if they reside in the same bin. In reality, this is no different than labeling each bin with an ℓ-bit binary string and claiming two agents are in the same group if their binary string labels match. Hence, the McDonald and Sen model and the Hales tag models are identical.

The payoff rewards used in McDonald and Sen model were $T = 1.9, R = 1.0, P = 0.002$ and $S = 0.001$. In the Hales model these were $T > 1, R = 1$ and $P = S = 0.0001$.

T3 tags were not evaluated in this research effort for reasons that will be discussed in Section IV. They are included here merely to inform the reader of past research on tag-mediation.

III. Experiments

All simulations used a population size of $N = 400$ and payoff values of $T = 300, R = 200, P = 100$ and $S = 0$. (These payoff values have previously been used for ISD studies [5].) The same seed for the random number generator was used in all simulations to make fair comparisons.

All experiments were conducted in the following manner. Let C and D be represented by the two dimensional unit vectors

$$s = \begin{pmatrix} 1 \\ 0 \end{pmatrix} \text{ and } \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

respectively. Tags partition agents into groups with agents with matching tags belonging to the same group. During each round an agent randomly chooses an opponent from the population. Play begins if the opponent belongs to the same group. However, if the opponent is not in the same group another opponent is randomly chosen. If no opponent with a matching tag is found after a fixed number of attempts (N_T), one more opponent is randomly chosen and the two agents are forced to compete[2]. Self play is not permitted. The agent x and his opponent y play N_m times and both accumulate payoffs. (Agents do have the option of changing their play each time.) The accumulated payoff for agent x is

$$\text{payoff } (x) = \sum_{k=1}^{N_m} s_x^{\mathrm{T}} Q s_y$$

where Q is the payoff matrix. The total payoff to x is the sum of the payoffs accumulated over all rounds of play.

A. T1 tag experiments

The tag and strategy genes were mutated by adding a normally distributed random variable with zero mean and variance 0.01 to the current value. Circular mutation was used for the tag gene ($\mathcal{T}$) while the strategy genes (i, p, q) mutation was hard limited to the boundaries.

Recall agent x agrees to play y with probability $1 - d_{x,y}^b$, where b is a bias value. Riolo [12] chose bias values from 0 (the no tag case) up to 100. Bias values much less than 1.0 means tag values must be approximately equal for play to occur. For this experiment we used a bias $b = 0.2$, which seemed a reasonable compromise value. Both agents must agree to play for competition to take place.

During each generation each agent gets a turn as the focal agent. The focal agent randomly selects an opponent. If they do not both agree to play then another opponent is randomly chosen. This process is completed $N_T = 5$ times. One more random pick is made if no opponent was found but this time the two agents are forced to compete. The competing agents play $N_m = 4$ times, using the i, p, and q genes to determine whether to play C or D. Agents accumulate payoffs each play.

The next generation were selected by binary tournaments (based on accumulated payoffs). Each selected agent was subject to mutation with a 10% probability. The three strategy genes and the tags were mutated by adding a normally distributed random variable. As described previously, the tag gene used circular mutation whereas the strategy genes were clamped at the boundaries.

Figure 1 shows how the no tag case (where players randomly choose an opponent and they are forced to play) and the T1 tag case. Clearly tags improve the population cooperation levels when compared to no tags.

B. T2 tag experiments

Each player had i, p and q genes which had the same function as in the T1 tag experiments. Agents randomly chose two tags from the integer tag set $\{1, 2, \ldots, 200\}$. This tag set was not too large given there are $N = 400$ agents. During each round an agent would compare tags with the $N - 1$ other agents and compete against those which had at least one matching tag. Agents played four times and payoffs were accumulated. Figure 2 shows multiple integer tags produce higher cooperation levels.

[2] In the no tag experiments, an agent randomly chooses an opponent and the two agents are forced to play.

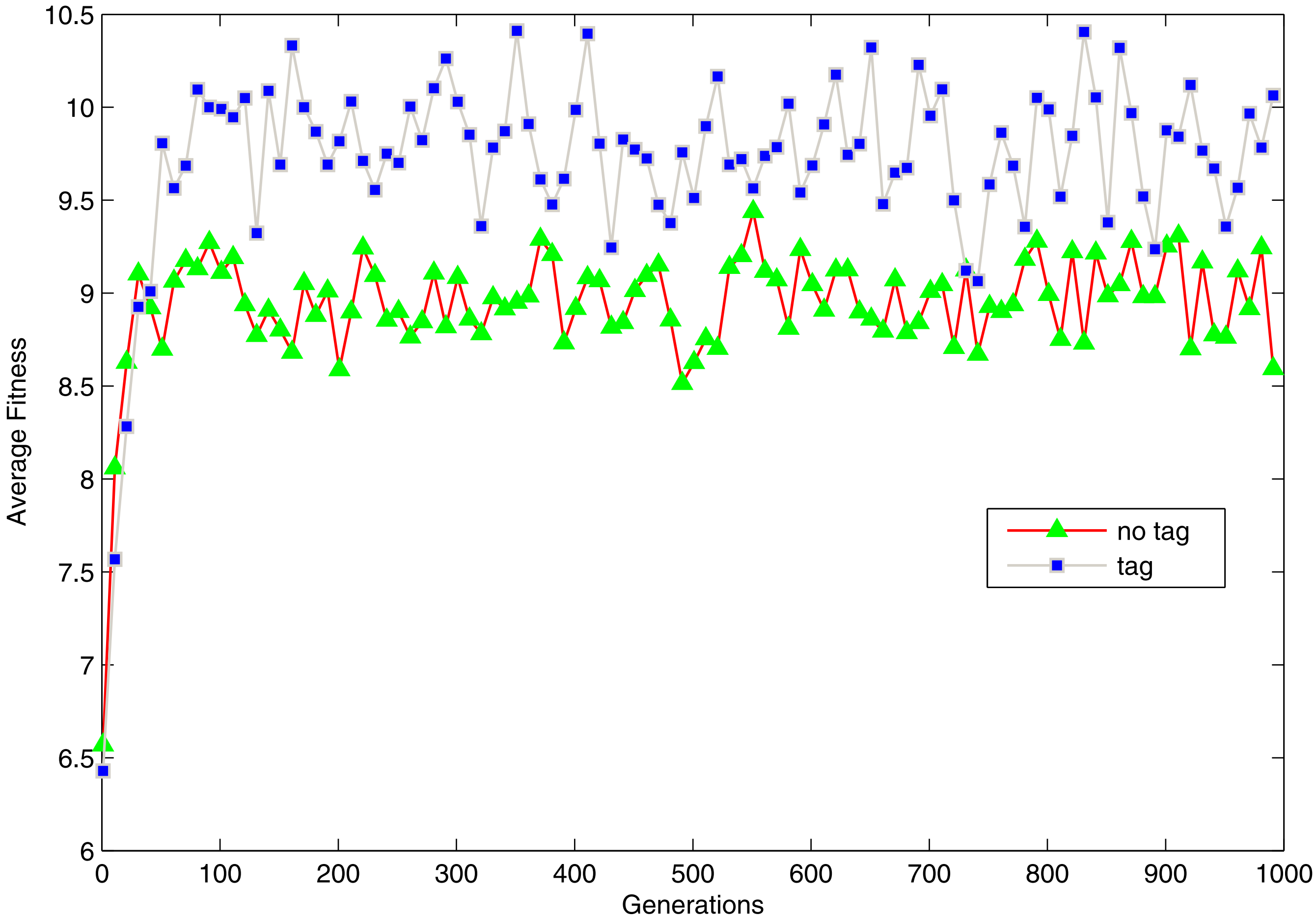

Fig. 1. Cooperation in a population with T1 tags compared against the no tag case. The bias value was fixed at $b = 0.2$.

Similar to the T1 tag experiments the next generation was selected with binary tournaments and agents were subject to a 10% probability of mutation. The tags were mutated by randomly choosing a different tag from the tag set.

IV. Discussion

A survey of recent literature on social dilemma games indicates the N-player games are starting to dominate the traditional 2-player games. One reason is N-player games are better able to model real world situations. Tag mediated games are N-player games so it is important to see where they fit in.

The two extremes are the well-mixed populations where every agent can compete with every other agent with some positive probability. There are real world situations where these conditions exist; the quintessential example is Hardin's tragedy of the commons [16].

At the other extreme are the so-called "spatial games" where agents are placed on nodes of a regular graph and only interact with their local neighbors with periodic boundary conditions. For example, the graph is a 2-D lattice and agents only interact with their north, south, east and west neighbors. These spatial games are becoming less emphasized because they create artificial situations with little relevance to the real world. Indeed, it is hard to imagine a real world scenario where a large population is partitioned into very small, equal size groups.

In the middle are the small-world networks and the scale-free networks. Small-world networks have a small variation in group size. All agents are placed on nodes in a regular graph and then a small subset of players receive one or two additional graph edges, thereby forming a slightly larger group. The scale-free networks place a few agents in very large groups while the majority are in small groups with only one or two neighbors. The scale-free networks can model many diverse real world scenarios.

But all of these spatial networks suffer from one major flaw: they are rigid structures that fix group membership. Agents cannot easily switch groups.

Tag mediated games, on the other hand, provide an oppor-

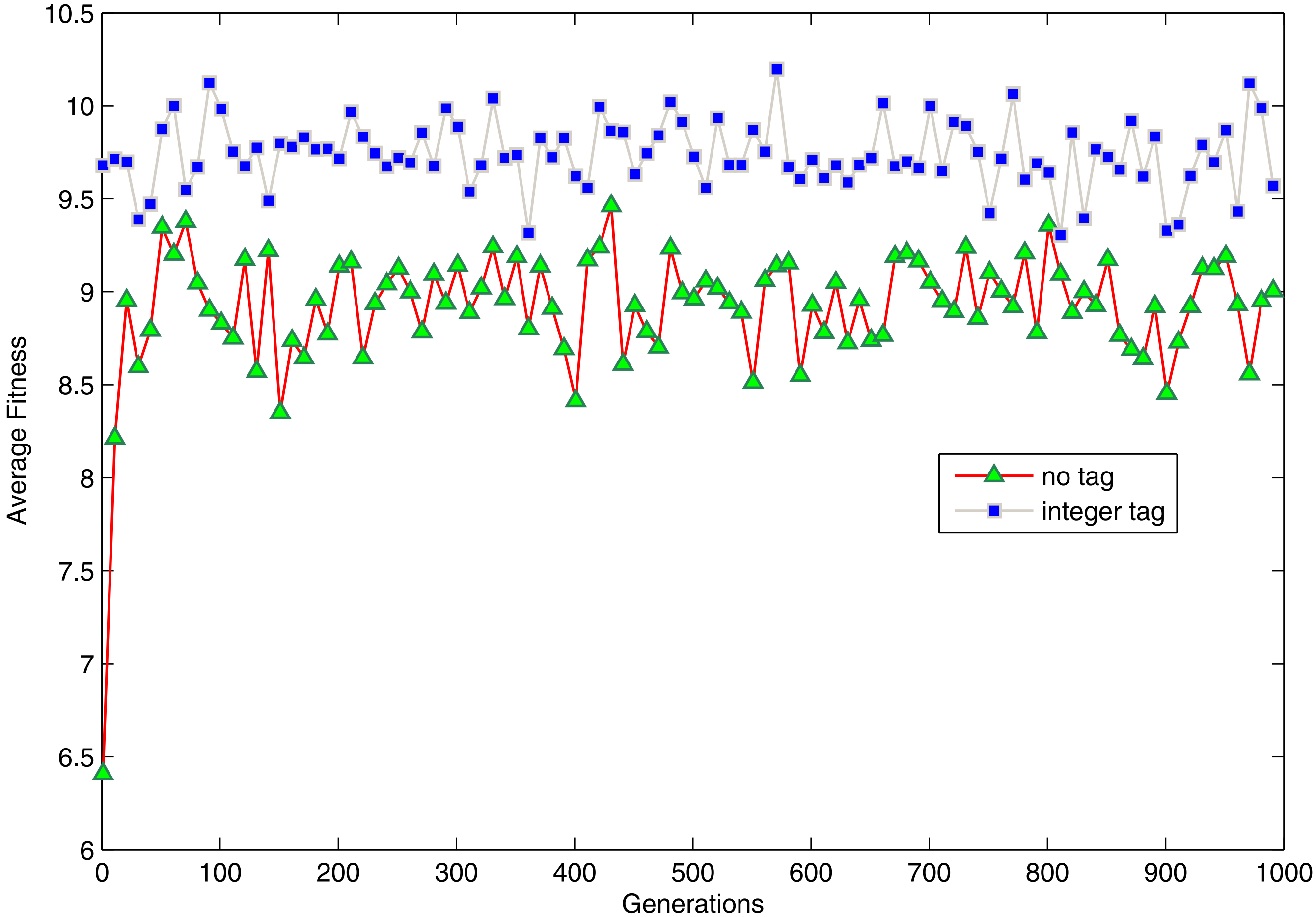

Fig. 2. Cooperation in a population with multiple integer tags compared against the no tag case.

tunity for dynamic group size changes. Tags naturally form groups but their real advantage is agents can easily move to other groups by simply modifying their tag. This allows agents to leave groups where they perform poorly and move to other groups where they might prosper. This ability to dynamically change group sizes helps tag mediated games mimic real world scenarios much better than spatial games where group sizes remain fixed.

Tag mediated games—particularly the T1 and T2 tags—also let agents change strategies in repeated encounters with the same opponent through their p and q strategy genes. This capability provides a natural framework for reciprocity investigations.

Agents in the same group have matching tags. The definition of a matching tag depends on the type of tag. In T1 tags the tags are real numbers on the unit interval. Two tags match if they are close in a Euclidean sense with a tag bias value giving a threshold for closeness. T2 and T3 tags require the tags to be equal to match. For practical reasons this requirement imposes a limit on the number of distinct tag values. If there are too many possible tags it will be virtually impossible to find an agent with a matching tag and therefore difficult to form tag groups. This is a fundamental problem in both the Hales and the McDonald and Sen models because they use 32-bit binary tags. This length means agents can have over four billion possible tag values.

In the T1 tag model the bias value determines how close the tags must be to compose a match. Low bias values restrict interactions to mostly tag group members. In Riolo's work [12] bias values went from 0 to 100 although it is not clear why such a large range was picked since bias values above 4 or 5 effectively means tags become irrelevant when choosing an opponent.

In certain circumstances an agent may want a low bias value. If an agent's group is mostly cooperators a low bias value will tend to keep the agent in that group, which would be desirable. But if the agent is in a group of mostly defectors it would be better to have a high bias value to help switch to another group.

We conducted an experiment with T1 tags where bias

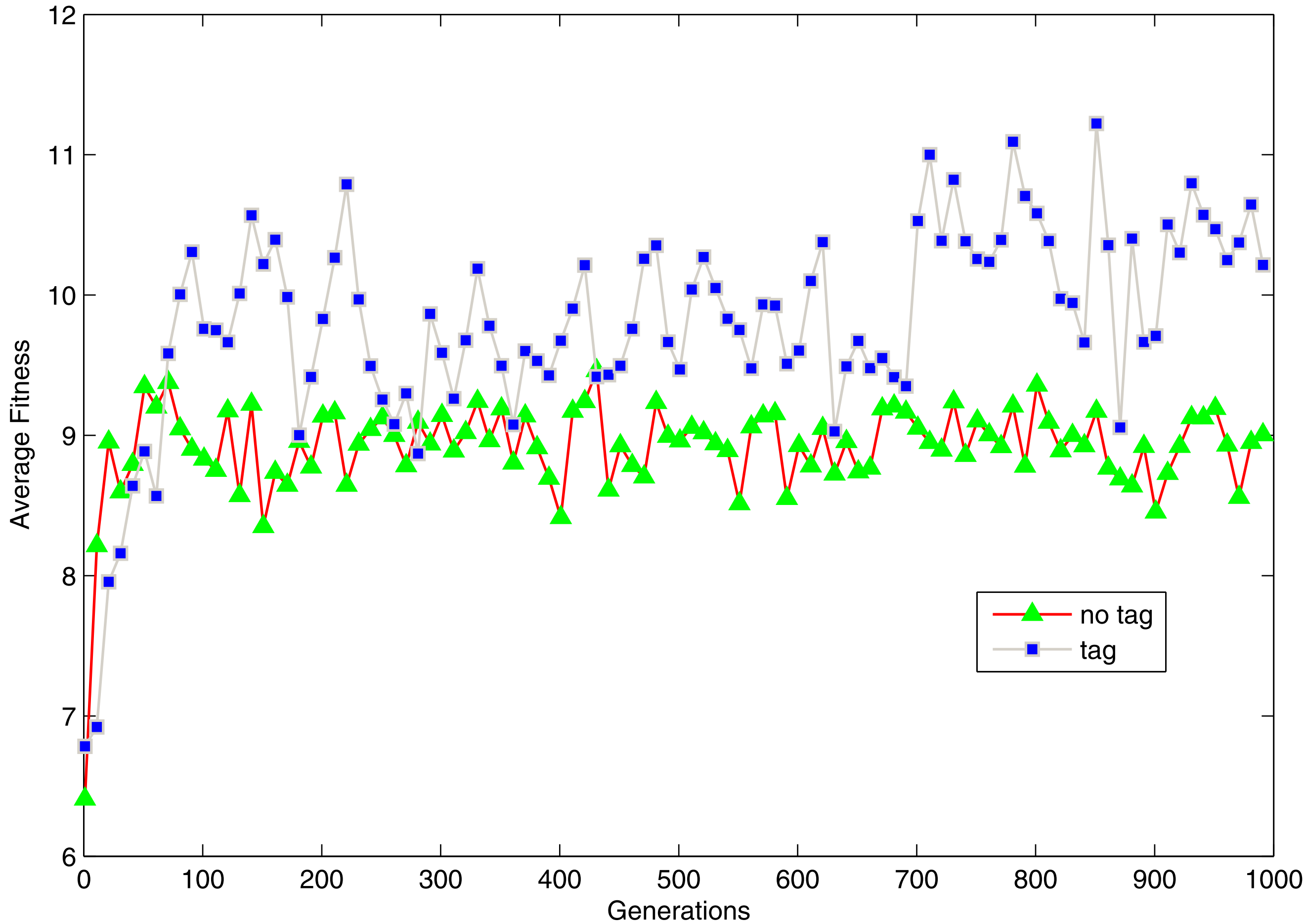

Fig. 3. Cooperation in the population with adaptive tags compared against the no tag case.

values were adapted with a 10% probability but the range was constrained to $b \in (0, 2]$. Figure 3 shows that adapting the bias causes more variance in the population cooperation levels but does lead to higher cooperation levels than with a fixed bias (*c.f.* Figure 1). Figure 4 shows how the average bias value changes. Notice the average adapted bias value tends to stay relatively low, never even approaching the upper bound of 2.0. This suggests the large bias value range Riolo used was probably unnecessary.

Tag mutation is essential for maintaining high cooperation levels in the population. Agents favor competing with members of their same group. A group of all cooperators will tend to grow although this group could be successfully invaded by a defector. Eventually the group would consist entirely of defectors, which would result in group extinction. Thus, in order to survive a cooperator must move to another group before that happens and tag mutation provides the necessary escape mechanism. Changing groups to survive is reminiscent of the *red queen effect*. This effect was introduced by Van Halen [17] who believed species could survive in a co-evolutionary system only if they constantly adapt to maintain their fitness with respect to other species.

Self play makes little sense in the SD game. With only one player the choice is simple: get out of the car and shovel snow so you can get free, or stay in the car and get hypothermia. There are no other options, making cooperation the obvious choice. (Put another way, why would you ever choose not to cooperate with yourself?)

T3 tags were not evaluated. For one thing a binary string tag is really no different than an integer tag and we were evaluating multiple integer tags anyway. But the real reason why we did not test the Hale or the McDonald and Sen models is because their model formulation deviates so much from other tag mediated work it is hard to put their work in perspective. Frankly, these models don't provide much insight into how tags might promote cooperation in social dilemmas. This remark is not meant to be overly harsh, but the reader should consider the following two aspects of those models:

1) *Payoff disparity*

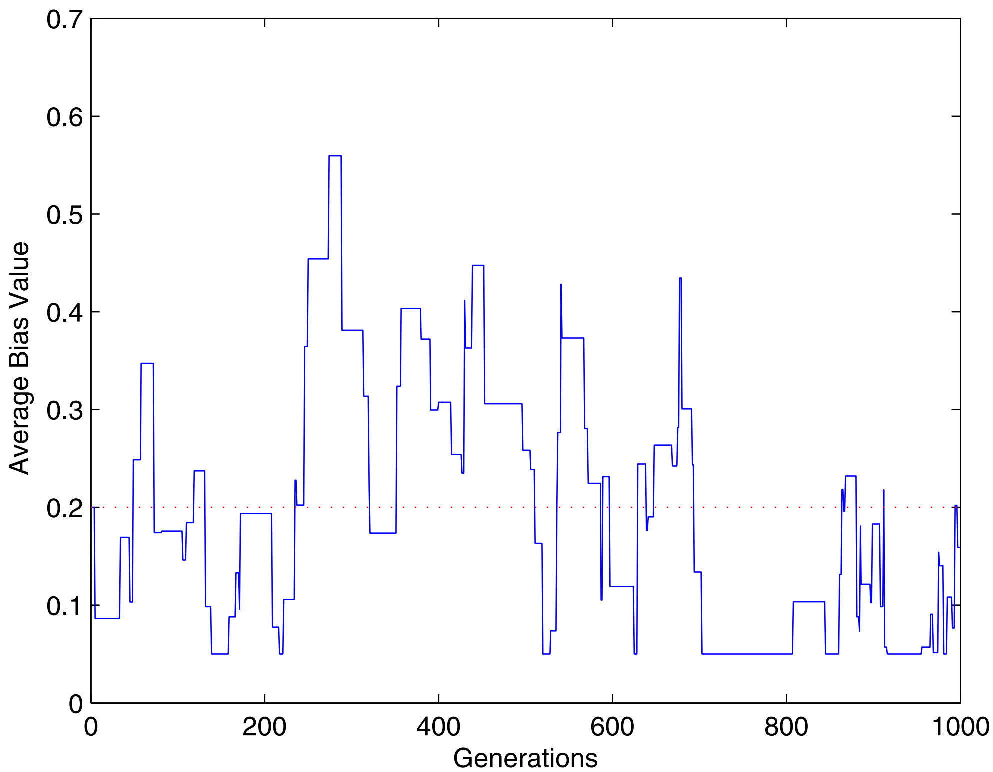

Fig. 4. This plot shows how average bias values change over time. The dashed line at $b = 0.2$ was the fixed bias value level used for the previous T1 tag experiments described in Section III-A.

The payoff for T or R is three orders of magnitude higher than a payoff for P or S in the McDonald and Sen model and four orders higher in the Hales model.

2) *No reciprocity*
Neither model provides any capability for assessing the effects of reciprocity (direct or indirect).

We are not aware of any other work that had such a huge difference between the payoffs of the (T, R) and the (P, S) pairs. First of all that magnitude of difference blurs the distinction between ISD and IPD. But a second even more important issue is present. Frankly, we are puzzled why anyone would choose such a huge difference because any claims about tag performance in a social dilemma game are a pretense. In fact, three or four orders of magnitude difference completely destroys any notion of a social dilemma!

The problem with T and R being orders of magnitude higher than P and S is the survival rule under roulette wheel selection becomes rather trivially obvious: play against a defector and you die; play against a cooperator and you live. In other words, it really doesn't matter whether the focal agent chooses *C* or *D*—the only thing that matters is what choice his opponent makes. *Hence, a dilemma no longer exists.*

It is easy to see how the dilemma is removed by comparing the slot widths in a roulette wheel. An agent who plays against a cooperator gets a slot width roughly a thousand times wider than if he played against a defector[3]. These relative slot widths hold regardless of whether the agent plays *C* or *D*; the agent therefore faces no real dilemma. On the other hand, with our choice of T, R, S and P, the difference in slot widths for a cooperator playing another cooperator is only twice that of playing against a defector. Now the agent does have a dilemma because playing a defector doesn't automatically imply extinction.

Another limitation in the Tag 3 models (and another reason why we did not evaluate it) is there is no provision for incorporating reciprocity. In those models the strategy is fixed over a entire round. Thus the agent derives no benefit from multiple encounters and cannot exploit information from past encounters. Conversely, in the T1 and T2 tag models an agent plays the same opponent N_m times and can modify his next play accordingly because of the p and q strategy genes.

Finally, it is worth mentioning 10 years ago Riolo et. al [18] proposed a slightly different tag mediated game. Each agent x had a tag $\tau_x \in [0, 1]$ and a tag "tolerance" parameter T_x. Agent x donates to agent y if $|\tau_x - \tau_y| \leq T_x$. Agent y receives a donation b and agent x pays a cost c. Both tags and tolerance parameters could evolve. Their model showed high levels of cooperation could be evolved without any reciprocity. Subsequently Roberts and

[3]Applies to the McDonald and Sen model. For the Hales model this increases to roughly ten thousand times wider.

Sherratt [19] exposed a problem with the Riolo et. al model: if the tag difference was less than the tolerance, then agent x was *forced* to donate. In other words, agents always cooperated if the tags matched and always defected if they didn't match. Roberts and Sherratt conducted experiments showing the cooperation levels significantly deteriorated if agents had the option of not donating—even if the tags were equal. They (correctly) concluded cooperation based on similarity was built into the Riolo et. al model and that's the reason they got such high cooperation levels without reciprocity.

V. Conclusions & Future Work

Previous experiments had shown tags can increase cooperation levels in N-player IPD games over the no tag case. (Not using any tags is equivalent to running the game with a well mixed population.) Our experiments indicate tags have the same effect in N-player ISD games.

In the real world agents change associations if they do poorly. One nice feature of tags is they model real world situations much better than spatial games since tags allow groups to naturally grow or dissolve based on how group member profits develop. The T1 and T2 tags also have strategy genes that provide a good framework for direct reciprocity studies.

We did not actually investigate the role of direct reciprocity in this work although it was inherent in the T1 and T2 experiments. This will be the focus of our next investigation. But an obvious extension would be to study indirect reciprocity as well. That should be easy to incorporate. Each agent could keep tract of how frequently they cooperated in the past (as a percentage). This information would be available to all agents and would represent the agent's reputation. That reputation could then alter other agents' p and q genes. For example, an agent who only frequently cooperates might cause opponents to temporarily lower their p and q strategy gene values, which makes them less likely to cooperate.

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