Tag-Based Cooperation in Networks

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Abstract

In this project we investigate tag-based cooperation, in particular the effect of network topologies in the emergence of cooperative strategies and dealing with malicious agents, i.e. agents that never cooperate.

We realized computer simulations of the donor/receipt setting [1, 2] introducing the possibility of defection for similar agents and using as the matching-tag a chain of bits. Random networks and small world networks were implemented to restrict the pairing between agents.

We find that a decrease of connectivity increases the donation rate when the game is played several times before the learning stage while when the network is connected, high cooperation only arise in an specific interval of number of pairings.

This behaviour can be explained for a general reduction in tolerance before a main-tag giant community or cluster is conformed. The increase in connectivity makes this cluster vulnerable to intolerant mutants attacks. Only low cost donations exhibit high cooperation. When the cost of donation is expensive, an increase in connectivity improves the donation rate.

The clustering degree does not play a relevant role in the emergence of cooperative strategies but is effective to neutralize the impact of malicious agents.

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1 Introduction

Social entities are complex systems. Any description of them typically deals with an apparent contradictory behavior. On the one hand, individuals are able to cooperate with other ones which have not any relation, on the other, they take practically any chance they can get to increase their profit even cheating.

In a game perspective, social organisms are cooperative and unselfish, then again driven by pure egoism. Besides, they also tend to behave in a risky manner once in a while without there even being a compelling necessity to do so. Humans are one of the best examples of this. But, how and why humans cooperate?

The emergence of cooperative strategies between individuals is commonly explained by direct and indirect reciprocity mechanisms based in agent's reputation.

Direct reciprocity occurs where two agents have repeated interactions, then is possible to return the coactive or selfish acts in kind ('I will help you if you have helped me before'). If the act are directed to someone else but not to us, reciprocity is named indirect ('I will help you if you have helped others before')[1].

As in a large society it is unlikely that a cheater is held to account by the victim, direct reciprocity cannot be sustained. Furthermore indirect reciprocity leads necessarily to "reputation building , morality judgment and complex social interactions with ever-increasing cognitive demands" .

Tag-based cooperation, in contrast, depends on the likelihood to help those who are similar to us and can be widely applicable when reputation is not established. Tag-based collaboration can lead to the emergence of cooperative strategies among agents with only a rudimentary ability of discernment and without memory of past encounters [2].

Tag-based cooperation has been observed in Donor/receipt general setting [1, 2] where agents have a certain number of opportunities to donate b with a cost c such that $c < b$. Donation is realized if the potential receipt is sufficiently similar to the donor according a donor's criteria: the tolerance threshold.

When both agents play simultaneously the role of donor and receipt the setting corresponds to Prisoner's Dilemma game, which have a cooperative equilibrium when agents play a deviation trigger strategy in an repeated game. However, the individuals act by separate and the trigger strategy cannot be implemented in a direct way.

If the number of agents is large, the interactions between same players are very unlikely. Besides, the information about the reputation of the complete population becomes huge and any kind of reputation mechanism is expensive. Instead that, after the whole pairing stage, each agent compares it strategy with a random agent and adopts it tag and it tolerance if has a bigger fitness.

Agents' tags and tolerances are real numbers equally distributed in the interval $[0, 1]$. Individuals cooperate when the distance between tags is less than donor's tolerance ($|t_i - t_j| < \tau_i$).

In a play every agent has specific number of opportunities of donate. After each play agents copy new strategies according their fitness (payoff). Tag and tolerance can mutate, an do it independently with a rate of 0.1, into a uniformly distributed number in $[0, 1]$ for tags while tolerance mutates helps also to maintain a moderately high degree of cooperation when the cost of donation is big while for cheap donations the biggest cooperation is observed for low connectivity networks presumably for the establishment of clusters adding white noise distributed in $\mathcal{N}(0, 0.01)$.

Under a biological approach this strategy corresponds to the branching of fittest genes in a population. In a social outlook, agents learn the most profitable strategy of those of they can observe.

In [2] is observed that as tag and tolerance are subject to mutation the clusters of similar agents are vulnerable to the invasion of non-cooperative mutants. Studies of the minimal representation of this model show that the system oscillates cyclically around states with different predominant tag, maintaining a dynamical diversity [3].

Pairing in [2] is done randomly in a fully connected network where agents are nodes. Some studies in the influence of network topology when mutation exists lead to believe that tag-based cooperation is not stable in regular, small-world nor random networks, but exist some features which promote specific dynamics [4].

So far has been assumed that all the agents in the setting strictly follow the donation rules imposed by their tag and tolerance. But certainly in a social system is possible that exist malicious agents that do not cooperate even if the rules dictate that they should.

The effect of cheaters have been analyzed by Griffiths assuming that the offspring of a malicious agents will be malicious too and that cheaters do not falsify their tag. In standard tag-based cooperation introducing even small proportion of cheaters into the population causes cooperation collapse [5].

In order to counter the effect and spread of cheaters has been suggested a mechanism based in limited image scoring but only in the neighbourhood where the agents interact named context awareness [5, 6]. Cooperation have also been improved with rewiring methods where edges not cooperative agents are removed and new connections based on the experience of others are added [6].

In this work we explore the influence of specific network topologies in the emergence of tag-based cooperation when the tag corresponds to a finite set of binary characteristics. Furthermore, the capacity to preserve cooperation in the presence of malicious agents is tested for selected networks. In the following section the employed model is described in detail.

2 Model

The model was extended to use chains of bits of length L as tags instead a real number. Tolerance is represented as a real threshold in the interval $[-|\epsilon|, L+1]$ where $\epsilon = 10^{-6}$. The relevance of this interval is that agents can eventually defect even if the potential receipt is identical. Introducing this possibility of defection results in a reduction in the donation rate [7]. Nevertheless the above, this modification provides a more realistic social model.

Instead a real number between zero and one a chain of bits is used as tag matching mechanism. This chain of bits represents a set of public binary characteristics which agents use to compare themselves with the rest and evaluate if are enough similar or not (democrat or republican, local or foreign, healthy or ill, etc). When the number of bits i.e. the length of chain diverges the tag is reduced to the original matching mechanism.

This idea was used before by Matlock and Sen in [8] for some extensive games between agents (Prisoner's Dilemma and Anti-Coordination). In this case, before donate, agents compare each one of the cells of the potential receipt's bit chain with their own. Some of these fields are indifferent for the agent, which means that if the bit of the other agent is different there, this is simply ignored. The main claim about the previous tag mechanism based only in a number is that is constrained to be self-matching types, thus an agent only interacts with other agents with identical or similar tags.

Instead fix "indifferent fields" for the tag, agent tolerance is defined with an threshold which limits the number of fields in which donor and receipt can differ, and still allows the donation. On the contrary with [8], no hierarchy nor distinction was imposed in agent preferences of its own features.

Both mutation methods are the same as in [2].

The network restriction on agents' pairing emulates more realistically the way that individuals use to interact: A neighbourhood determined by a physical or unphysical distance. When pairing is done in a network, this is restricted only to the first neighbours. During the learning strategy stage the network does not play any role and the fitness comparison is realized selecting a random agent. The basis of this selection is that learning in a real context could occurs no exclusively between related agents but by references or by public exposure. As in [5] a cheater is defined as an agent that do not donate in any circumstances. Malicious agents are supposed spread their behaviour after replication and to be honest about their tag and tolerance.

2.1 Set up

The results presented here represent an ensemble average of 100 runs using a population of 100 agents. Each run consists in the time average of 30000 generations after the first 100 generations (stabilization time). Agents' tag is a chain of bits of length $L = 40$. This parameter was chosen after test different values of L with no significant increasing in donation rates achieved for tested bigger values.

The game is played in random networks and small-world networks. Every random network is generated stochastically with the $G(N, p)$ Erdös Renyi model [9] where each possible edge between the N nodes has an equal and independent probability $p \in [0, 1]$ of exists. To generate small-world networks was used the Watts-Strogatz algorithm [10] where, starting with a regular ring lattice of N nodes, each one connected to K neighbours each side, every edge is rewired with probability $\beta \in [0, 1]$ avoiding loops and duplication.

The benefit of a donation is fix in $b = 1$. The number of pairings P and the cost of donation c are modified independently for several settings.

Cheaters are introduced with an attribute of agents that could be learned or copied in the replication stage. This attribute is not subject to mutation.

3 Results and discussion

3.1 Random networks

The effect of the Erdös Renyi probability p and the number of pairings P in the emergence of cooperation is illustrated in Figure (1) for a cost $c = 0.3$. The first graph consists in the matrix of the values of donation rate for each one of the pairs (p, P). Besides this are included some plots of the donation rate dependent on P for fixed values of p and the donation rate dependent on p for fixed values of P. The used values are selected to make evident the behaviour of cooperation in the setting.

Is evident that the value of P where the donation rate is maximum varies with p. An increase in connectivity only implies an increment in cooperation if $P \leq P_c = 12$. For bigger values of P the donation rate decays drastically with p. In therms of Erdös Renyi probability, only when $p \leq p_c = 0.2$ a bigger number of pairings implies a greater cooperation.

A decrease in the cost of donation to $c = 0.1$ moves the critical values to $P_c = 10$ and $p_c = 0.1$ as shown in Figure (2). As expected the donation rate increases when cost is reduced for most of the cases.

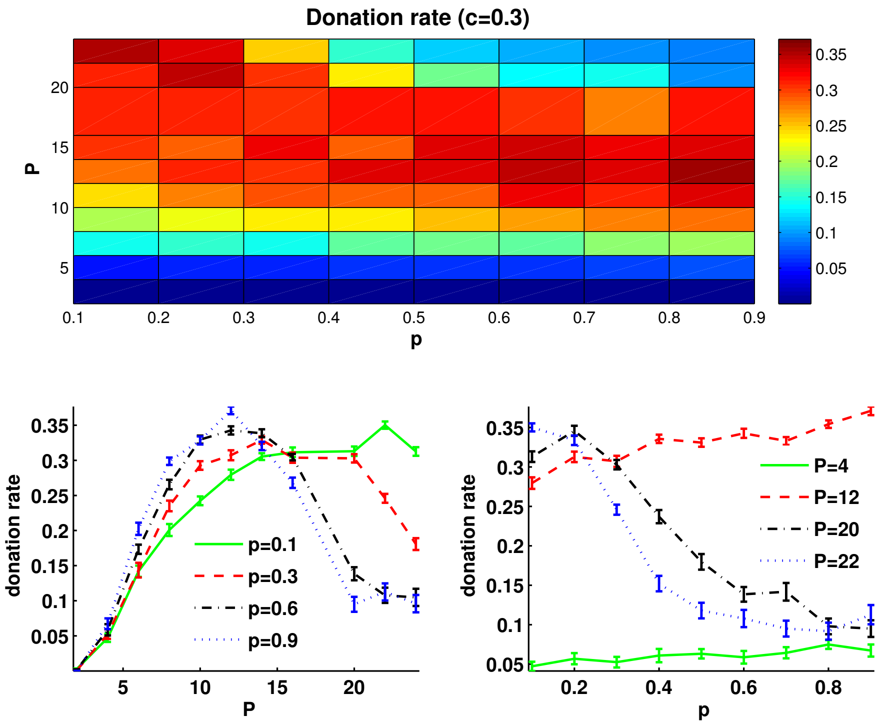

Figure 1: Effect of the number of pairings P and Erdös Renyi probability p in donation rate for a cost of donation of $c = 0.3$.

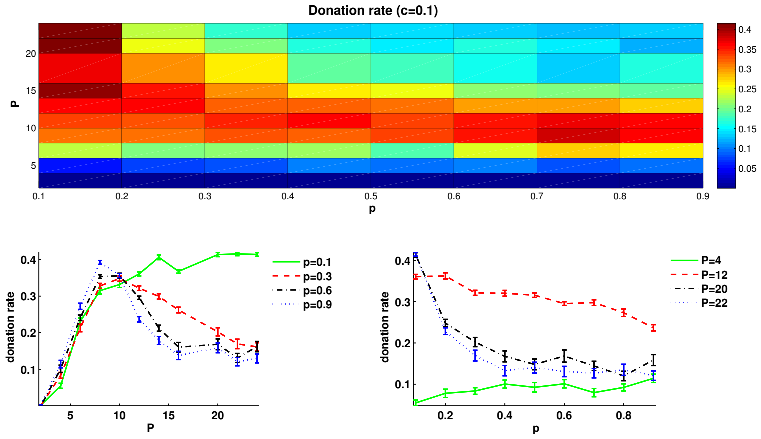

Figure 2: Effect of the number of pairings P and Erdös Renyi probability p in donation rate for a cost of donation of $c = 0.1$.

The effects of the cost of donation in cooperation was explored in deep. For $P = 12$ the behaviour of donation rate changes around $c_c = 0.2$. For given values of connectivity the cooperation declines when donation becomes more expensive. In this case, an increase in connectivity promotes a higher donation rate as is shown in Figure (3). In this figure c is used as parameter instead P.

To understand how cooperation is established we must refer to the donation dynamics.

When the game starts and all the tags and tolerance are randomly established, the probability that an agent donates is

$$p_d\left(t_j \mid t_i, \tau_i\right) = P\left(t_i\right) P\left(\tau_i\right) P\left(\left|t_i - t_j\right| < \tau_i \mid t_i, \tau_i\right). \tag{1}$$

As the number of possible tags is 2^L , the probability to select any of them is 2^{-L}. The distances between random tags are random variables in a symmetric binomial distribution $d \sim \mathbb{B}\left(L, \frac{1}{2}\right)$ then for a given distance τ

$$P\left(\left|t_i - t_j\right| < \tau\right) = P(t_i) P\left(\left|t_i - t_j\right| < \tau \;\mid\; t_i\right) = 2^{-L} F\left(\tau \mid L, \tfrac{1}{2}\right). \tag{2}$$

From Eq. (2) the donation probability only depends on tolerance τ_i when the tags are equally distributed at the beginning of the game. The probability to receive a donation is

$$p_r\left(t_j, \tau_j \mid t_i\right) = P\left(t_i\right) P\left(\left|t_i - t_j\right| < \tau_i \mid t_i\right), \tag{3}$$

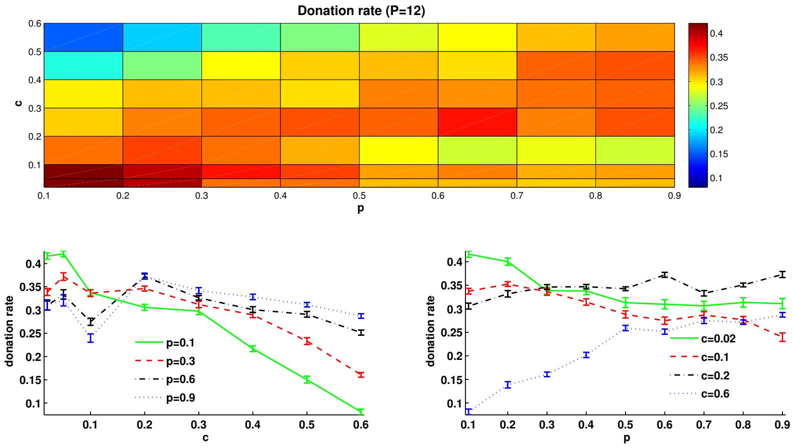

Figure 3: Effect of cost of donation c and Erdös Renyi probability p in donation rate for a number of pairings of $P = 12$.

which corresponds with Eq.(2) before play. In general this is true when the diversity of tags is high.

After a play stage, the fitness of the agents depends on the number of times its neighbours donate to it and the probability of be a donor only is reflected in fitness when the cost of donation is big.

For a game in a network with given connectivity every agent has in average Np neighbour nodes with whom it can play. Althought a large neighbourhood do not increase the chances to be a potential receipt, it can increase the number of successful pairings assuming high diversity. So far no agent has any advantage.

After stabilization agents with lightly lower fitness modify their strategy to form clusters of agents with the same tag, then the tag distribution must to be included in Eqs. (1) and (3).

Figure (4) exemplifies the changes in tag diversity (in this case is used a tag of $L = 10$ for visualization purposes). Top graph represents the existence of each one of the possible 2^L tags during 3000 generations. Last plot shows the number of tags and the donation percentage over the same period.

From here, three dynamic behaviours are evident: a large diversity stage (number of tag close to N) where the cooperation is almost zero, followed for a very cooperative period where only few tags survive (in different simulations this stage seems to be present even for many generations), and finally an intermediate stage where the number of tags oscillates and so does the cooperation.

The last two stages have typically a tag which is present all the time, presumably a main cluster tag. The vanishing of this tag is followed always with a jump in the

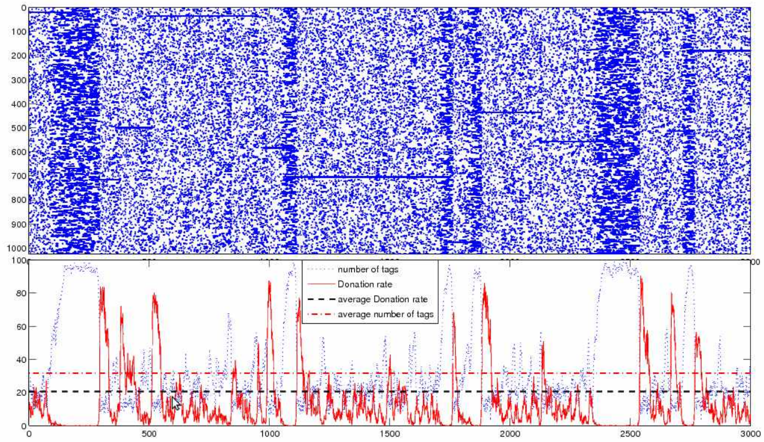

Figure 4: Tag dynamics of a typical run in a random network for 3000 generations establishing as tag a chain of 10 bits. Plotted rates are the number of agents (dotted blue line), percentage of donation (red line) and the average of both (dot-dashed red line and dashed black line respectively) during the whole process of 30000 generations. The implemented parameters are $N = 100$, $c = 0.1$,$p = 0.9$ and $P = 12$.

donation rate. This suggests the extinction of a cluster of agents due to the invasion of non-cooperative mutants.

In Figure(5) is shown the tag dynamics of typical runs for cooperative parameters according the results in Figure (2). The three explained stages are present in different proportions in both cases.

The clusters are not relevant in the pairing network.

The agents with a non-predominant tag need a high tolerance of the rest of agents to survive while the main tag ones prefer a moderate tolerance such that ensure the donations only into the group.

If there is still some diversity in the population is possible to receive a good profit for the interactions with agents out of the cluster, then the evolutive advantage of the individuals in the most populated group is reduced. That can explain the intermediate stage in tag dynamics observed in Figures (4) and (5).

Once diversity drops much is very likely to find agents with a unique predominant tag in every agent's neighbourhood.

Assuming that a less connected network promotes a reduction on tolerance even

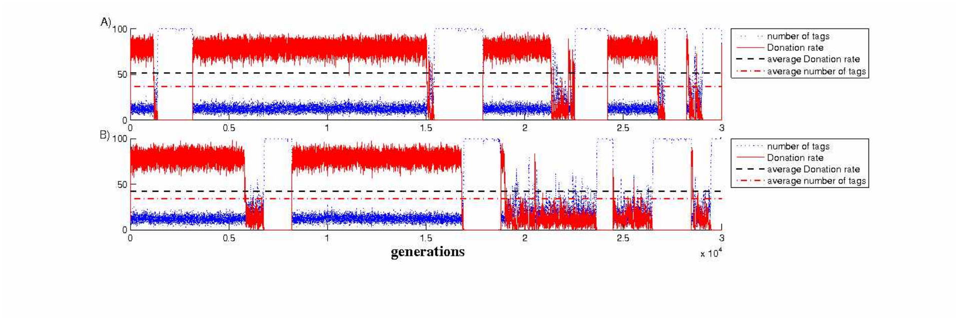

Figure 5: Number of agents (blue dotted line), percentage of donation (red line) and the average of both (dot-dashed red line and dashed black line respectively) during a typical setting run over 30000 generations. The implemented parameters are A) $N = 100$, $c = 0.1$, $p = 0.1$ and $P = 22$ and B) $N = 100$, $c = 0.1$, $p = 0.9$ and $P = 10$.

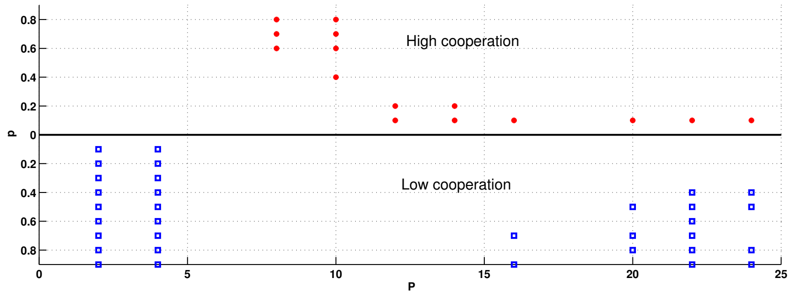

Figure 6: Map of high cooperative (red dots) and low cooperative phases (blue squares) for parameters P and p in a setting with a cost of donation of $c = 0.1$. High cooperation is defined as that phase where donation rate is bigger than 0.35 and low cooperation as that phase where donation rate is lower than 0.1.

before a predominant tag is established is understandable that the unique clusters are more stables for low p and that an increment on P only increases the cooperation.

When the connectivity of the network grows, the bigger neighbourhoods induce the intermediate stage of tag dynamics since main groups are conformed with moderately tolerant individuals. This clarifies why an increase on P can eventually make the cluster vulnerable and so reduces the donation rate.

An expensive cost of donation makes the intolerant strategies more profitables. A connected network can facilitate the cooperation for expensive donations but in any case exists a high cooperation phase for expensive donations (Figure 7).

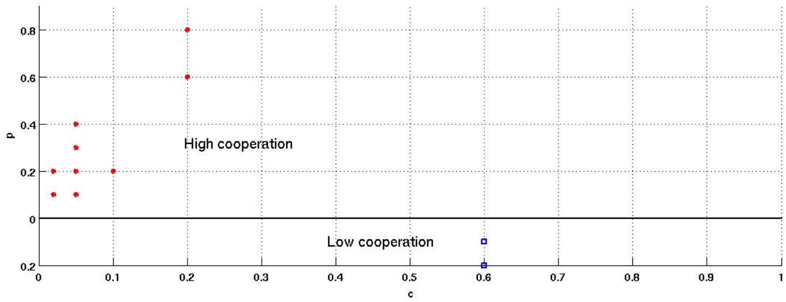

Figure 7: Map of high cooperative (red dots) and low cooperative phases (blue squares) for parameters c and p in a setting with a number of pairings of $P = 12$. High cooperation is defined as that phase where donation rate is bigger than 0.35 and low cooperation as that phase where donation rate is lower than 0.1.

3.2 Small world networks

The effect of the rewiring coefficient β in donation rate was analyzed. As for each number of neighbours per node $k = 2K$ corresponds a value of connectivity p, the values of donation rate are compared for seetings with $K = 15$ in a small world network and with $p = 0.3$ in a random network, and for $K = 25$ and $p = 0.5$.

The cooperation dependent on the number of pairings is very similar to the random network one for all the values of β. The relative changes in the donation rate associated to β are shown in Figures (8) and (9) for a cost of donation of $c = 0.1$ and $c = 0.3$ respectively. The graph corresponds to the change in donation rate measured in percentage versus P for many values of β.

In neither case exists evidence of an effect of β in cooperation. When the donation rate is dependent on c the parameter β only has a small influence in cooperation very low-cost donations as is illustrated in Figure (10). The graph shows the donation rates for several values of cost of donation in sub logarithm scale (for c).

Then, the changes in the clustering degree due to the small network topology do not provide any important advantage to cooperative agents.

3.3 Introducing malicious agents

The impact of malicious agents into the population is shown in Figures (11) and (12). The plots represent the donation rate for every pair (θ, p) and (θ, β) respectively, where θ is the proportion of cheaters in the population.

Is clear that when cheaters are introduced the cooperation is reduced. The connectivity does not modify substantially the donation rate in any case. In contrast

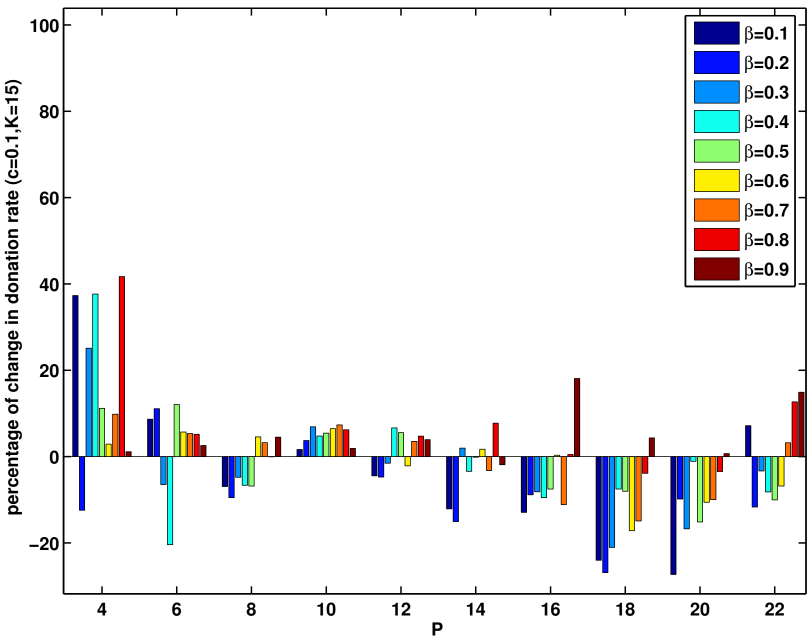

Figure 8: Effect of the number of pairings P and the rewiring probability β in donation rate for a cost of donation of $c = 0.1$ and an average number of neighbours per node of $2K = 30$.

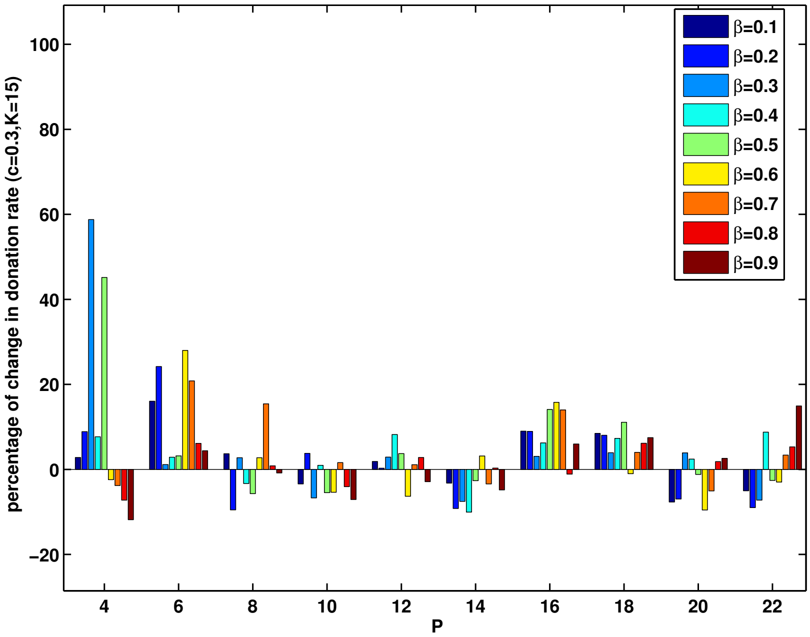

Figure 9: Effect of the number of pairings P and the rewiring probability β in donation rate for a cost of donation of $c = 0.3$ and an average number of neighbours per node of $2K = 30$.

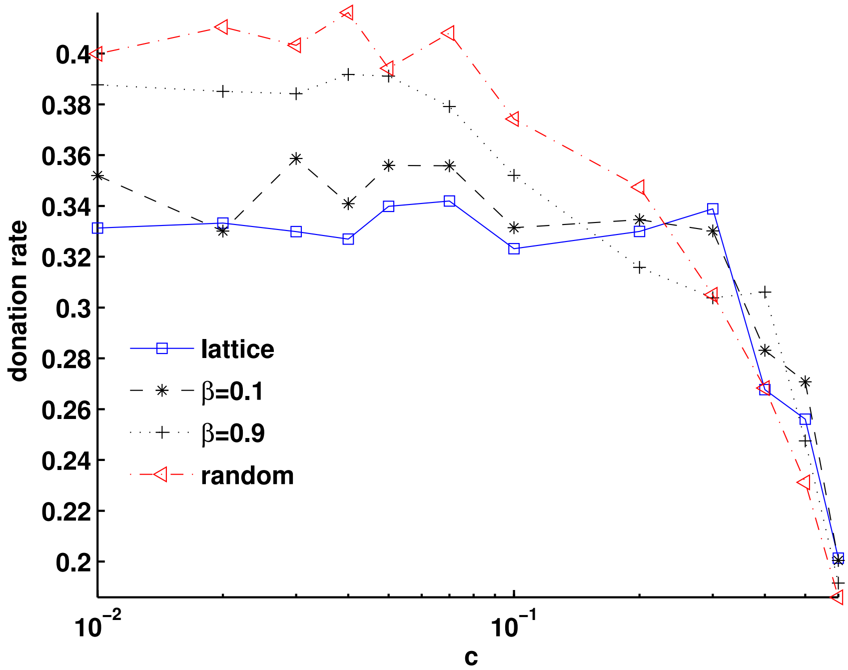

Figure 10: Effect of the cost of donation c and the rewiring probability β in donation rate for a number of pairings of $P = 12$ and an average number of neighbours per node of $2K = 30$.

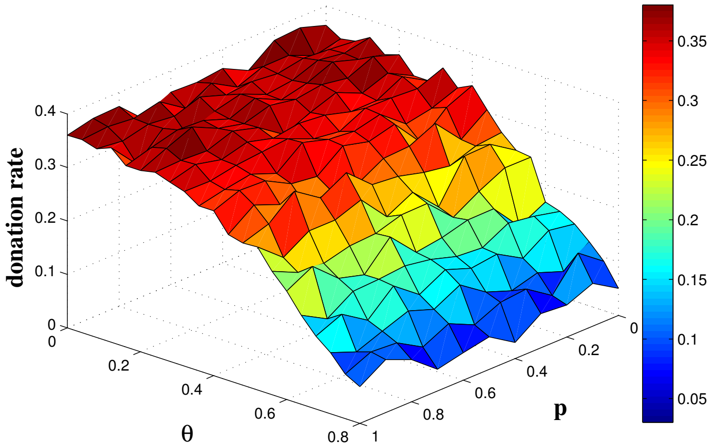

Figure 11: Effect of proportion of malicious agents θ and Erdös Renyi probability p in donation rate for a setting with 100 agents, a cost of donation $c = 0.3$ and number of pairings $P = 12$.

an small-world network topology can attenuate the decrease on donation due to cheaters existence when the rewiring rate β is enough small.

Then a high clustering degree on the network can maintain the comunities of agents enough closed to prevent a malicious agents attacks.

4 Conclusions

In this project we have analysed the effect of the network topology in the emergence of tag-based cooperation among agents when exists the probability of defection between identical individuals. Using a chain of bits as tag instead a real number as on Riolo et. Al. model, high cooperative scenarios have been identified for low connected random networks where the agents interact several times and for high connected graphs with a moderate number of pairings.

Cooperation when connectivity is low is explained by the formation of a cluster of same tag agents preceded by the reduction on agents' tolerance. High cooperation is supported in connected network only for an specific range of number of pairings per game. Only when the cost of donation is low is possible to establish a high cooperative phase. However is evident that when the cost of donation grows, a bigger connectivity improves the donation rate.

In a social system that means that when we restrict our interactions to few closest persons and we keep in contact frequently with them the global welfare increases

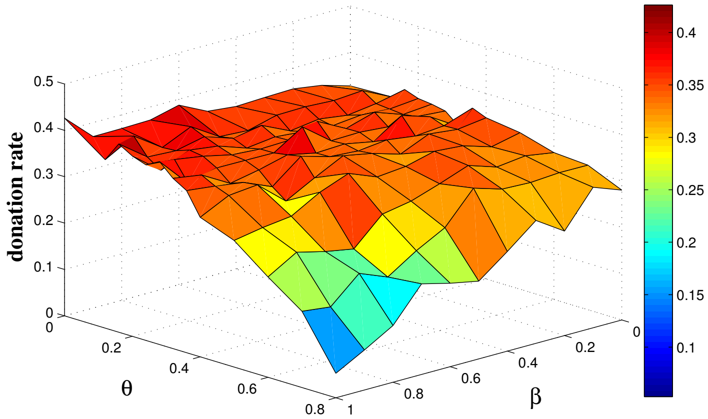

Figure 12: Effect of proportion of malicious agents θ and rewiring probability β in donation rate for a setting with 100 agents, a cost of donation $c = 0.05$,number of pairings $P = 12$ and number of neighbours per node of $2K = 30$.

and the sociaty becomes cooperative. In the case that we need to interact with a big community is better to moderate the number of interactions but never reduce it too much.

Altought an small world topology does not modify significantly the cooperation in the original model, a high clustering degree has seen to be effective dealing with malicious agents influence.

Translating the above into a real context we can say that only when we do not trust in the honesty of our whole community it worths to impose clustering in the interactions network.

4.1 Ongoing work

There are many possible areas of ongoing work but the main priority is to make a robust analysis to identify the parameters where a high clustering degree still promotes cooperation in the presence of cheaters. Is also necessary a theorical analysis of the reasons of the emergence of cooperation in a random network as the relationships between cost of donation, number of pairings and Erdös Renyi probability are not yet fully understood.

We also aim to explore the effect of dynamic networks in cooperation as well as the change in topology when agents implement rewiring mechanisms.

Future work will also consider realistic approaches for replication such that a not simultaneous learning stage for different groups of agents or introducing obstinates agents which never change their status of cheater or not-cheater.

List of Figures

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