Keep your enemies closer and be loud about it

Martin Toman; TUDelft
m.toman@student.tudelft.nl

Dr. Neil Yorke-Smith; TUDelft
n.yorke-smith@tudelft.nl

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1 Introduction

How can we encourage and sustain cooperation? Humans dominate their environments thanks to our ability to cooperate flexibly and at scale, as argued by Harari [7]. To study the conditions necessary for cooperation to flourish we need a suitable model of an activity with temptations to defect and punishments for doing so.

In 1950, Albert Tucker named a particular two-player exchange game "The Prisoner's Dilemma" [8]. This game elegantly captures the difficulty of the decision between cooperation and defection in a single choice. Despite being so simple compared to the complexity of the problem it is representing, it was used to model many aspects of behaviour in systems of selfish individuals; and, according to Axelrod [1], for "discovery of the precise conditions that are necessary and sufficient for cooperation to emerge".

In the case of a one-off exchange, there being no opportunity for a follow-up punishment, the rational behaviour is defection. (This extends to all rounds for a fixed-length game, inductively [1].) The interesting behaviour arises if there is no end; or, at least, if there is no way for the participants of the game to know when the game ends or even if there is an end. An agents has to expect that even a single defection can be infinitely punished by never again being cooperated with [5]. Such a risk may just not be worth it.

The defectors can, naturally, only be punished if they can be identified and known to others. This is why services like Ebay or Airbnb have a rating system in place. Presence of a reputation system has been shown to strongly boost cooperation, as shown by Camera and Casari [2], Stahl [14]. These studies used groups of volunteers as game participants and explored the effects of various information being public - from only the latest move of the current opponent, to full histories of all moves taken by every participant.

Using human subjects as game participants limited the research to relatively small groups with few rounds; they also used external infrastructure for information passing: eliminating noise, delays, and deliberately wrong information. As shown by Gevers and Yorke-Smith [6], not all strategies that perform well in noise-less environments can do so under the presence of noise.

Using external infrastructure for passing information also meant that the transmission speed was uniform for all participants receiving all necessary information in time for their next round of the game. These are non-trivial idealizations: relaxing them would yield a model closer to real-world systems and could change the results drastically.

In this paper we look at if and how well a local reputation system sustains cooperation and under what conditions does it yield optimal results. We evaluate the approach under various gossip range and memory length; and comment on the effectiveness of local reputation in enforcing cooperation in spatial prisoner's dilemma.

2 Methodology

We aim to measure the effectiveness of local reputation in enforcing cooperation. To do this we will build a computer simulation of a spatial multi-agent environment. We will use a Spatial Iterated Prisoner's Dilemma as the principal exchange game for modelling agent interactions.

In this section we define the goals of this paper explicitly, explain the design of the model and simulations, and present the measurable properties and evaluation criteria of the model. We end the section with an explanation of how we will connect our simulation results back to the original question and what would constitute a confirmation of our hypothesis.

2.1 Problem Statement

We will use the prisoner's dilemma game to model agent interactions. This is a good choice for modelling behaviour of rational and selfish actors. And will allow us to observe the conditions necessary for cooperation to emerge in the population as well as what makes it sustain itself.

The agents will live in a spatial environment and act independently; the only mutual interactions will be playing the game with a neighbor and exchanging gossip with nearby agents. We will vary the range at which the gossip can be exchanges as well as the amount of information which can be included in as single gossip message. We want to determine the effectiveness of the gossip mechanism in promoting and sustaining cooperation.

2.2 Simulation Design

To explore the effects of local reputation, built up via openly gossiping with nearby neighbors, we will use a computer simulation of a multi-agent spatial environment. We will base the simulation on the design of Smaldino et al. [13].

The model consists of a spatial environment: square grid with torus (wrapping) bounds, each cell can be occupied by a single agent. This is a discreet time model; at each time step, every agent takes a single turn. The order in which agents take their turn is randomized in each time step. Agent's turn is defined by the finite state diagram shown in Figure 1. The agents pay a fixed cost to survive ($c = 1$) to the next round (agents who deplete their energy die and are removed from the simulation), and try to reproduce once they accumulate enough energy via positive interactions with other agents: PD game wins.

Every agent can play at most a single PD game in each time step. Plating a game in the time step is not guaranteed and depends on the spatial configuration of agents, order in which the agents are scheduled, and randomness in choosing an opponent from agent's neighbors. Similarly, when no opponent is found, movement only happens if an empty cell is found nearby; if there is more than one empty cell, one is chosen randomly.

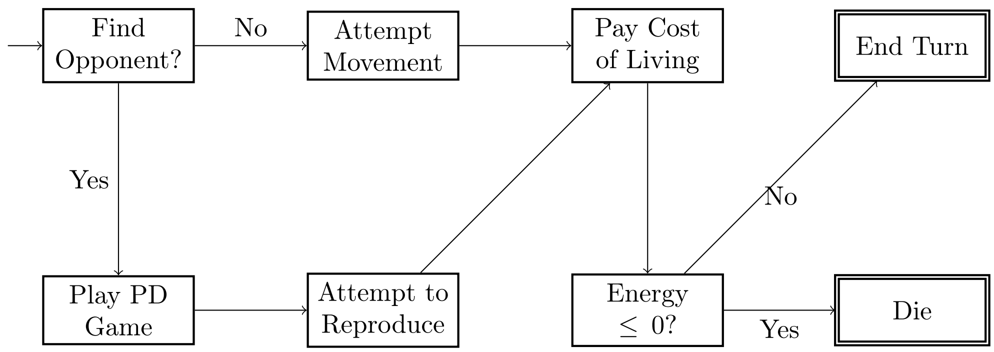

Figure 1: Agent behaviour diagram

Agents reproduce by creating a new agent with the same parameters as themselves in an empty neighborhood cell (chosen randomly if more than one, no reproduction if there are no empty cells in the neighborhood). Reproduction is only attempted if the agent has accumulated at least twice the amount of energy as is the cost of reproduction. The cost of reproduction is then subtracted from the parent and the offspring is birthed with this energy level. The cost of reproduction is effectively transferred from the parent to the offspring; reproducing does not change the net amount of energy in the model.

A single round of the game is defined using a payoff matrix as shown in Table 1, with $T > R > P > S$ and $2R > T + S$ [3]. Like in the original model, we will use $T = 5$, $R = 3$, $P = -1$, and $S = 0$ for all our simulation runs. We choose the punishment payoff value ($P = -1$), because this was shown in the original paper as a good middle of the road value and the cooperators struggled to survive under these payoff values. This choice of parameters will make sure that, if we reach cooperation, it was caused by the reputation mechanism; and not because of random interactions in the model.

Environmental harshness of the model is defined by the punishment payoff P (social harshness) and cost to survive c (external harshness). We will investigate the effect of varying these parameters on our results and check the effectiveness of gossip across environments of various harshness.

		Opponent's move	
		Cooperate	Defect
Player's move	Cooperate	Player: R Opponent: R	Player: S Opponent: T
	Defect	Player: T Opponent: S	Player: P Opponent: P

Table 1: Payoff matrix

To better suit our needs we will introduce some changes to the original model. We will reduce the spatial grid size from 100x100, as in the original design, to a more manageable 20x20. This will allow us to run more simulations with more complex agent behaviour in a manageable time. We will also decrease the starting number of agents from 1600 to 64: keeping the same ratio of 16% of the total grid size as in the original model.

This reduction of the environment size (by a factor of 25!) has the effect of significantly increasing the chance of a total extinction of all agents: caused by the random behaviour of agents exploiting each other until all cooperators are dead and the population of pure defectors cannot sustain itself. We disregard runs that end in extinction and increase the number of simulation runs to compensate for this.

We will expand the model by giving the agents a (limited size) memory to keep track of past defectors and later to allow them to actively and freely share this knowledge by gossiping with other agents in a given range. Prior research [9, 10, 11] has already shown that memory can be an effective tool in promoting cooperation.

Another expansion to the model will be the addition of the localized gossip mechanism. This will allow agents to consult nearby peers to try and find out the reputation of agents unknown to the agents themselves. The range at which agents can be contacted and the amount of information which agents provide will be varied. In the results section, an overview of the effects of varying the parameters of the gossip is shown. We believe this extension of the model will have a strong positive effect on sustaining cooperation in the model.

The simulation will be implemented in Python using the Mesa[1] framework.

2.3 Simulation Evaluation

To determine the effectives of gossip in promoting cooperation, we will observe the rate of convergence to a population of cooperators, stopping the simulation once stable equilibrium is achieved. To verify that this is indeed an equilibrium by letting the simulation run longer and checking that the general behaviour does not change. We will also observe the maximal population size of defectors which can sustain itself alongside the cooperators.

The main properties measured about the model will be the frequency of cooperators and defectors. We will measure both as the fraction of agents of the type alive in the model divided by the total carrying capacity of the population: 50% of all the cells for either type of agents. This is the same measure as used by the original paper [13].

Measuring both, the cooperator and the defector, frequency might seem redundant at first. However, the relationship between them is very highly nonlinear and depends on many factors; as will be shown in the results section.

We will also record characteristic patterns formed by the populations as influenced by different parameters. We do this, because it was shown by earlier work [12] that in Spatial Prisoner's Dilemma interesting patterns can emerge over time. These patterns are very similar to patterns occurring in nature, which are often created by reaction-diffusion processes. This suggests a deeper link between our model and natural processes.

3 Responsible Research

We recognize the inherent difficulties in conducting ethical and sustainable research. We take the following actions to ensure this paper is ethically good and can be reproduced by others, to provide a solid foundation for others to reproduce, reuse, and build upon this paper.

[1] https://github.com/projectmesa/mesa

3.1 Ethical aspects

This paper focused on exploring the effects of reputation on promoting and sustaining cooperation. We believe this research is ethically good and our conscience is clean about the methods used and conclusions reach, as well as all other aspects of this paper.

While we cannot ensure the findings of this paper will not be misused by others. We implore all reader's to always strive for the highest ethical ideals. Let's all be excellent.

3.2 Reproducibility

We want to make this paper a good foundation for future work and as such we provide all source materials for this paper: including the code files for running the simulations and evaluating results, the LaTeX files for this paper, and anything else used while conducting this research.

Next, we use Nix Flake[2] to capture the exact versions of all software, libraries, and packages used for this research [4]. All of this is captured together in and provided as a fully reproducible environment. We hope that by doing this it becomes easy to reproduce our results and provide a good foundation environment for other researchers to quickly kick-start their research.

Our model itself is implemented in a Jupyter Notebook[3] and care was taken to keep the total amount of dependencies as low as possible and to stick to the most standard dependencies whenever possible. We hope others will appreciate this by building upon our research and uncovering wonderful conclusions.

[2] `https://nixos.wiki/wiki/Flakes`
[3] `https://jupyter.org/`

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