Combined Effect of the Direction of Information Transmission and the Spatiality over Sustaining Cooperation

Ivette C. Martinez
Universidad Simón Bolívar
Departamento de Computación y T.I.
Caracas, Venezuela
martinez@gia.usb.ve

Klaus Jaffe
Universidad Simón Bolívar
Laboratorio de Comportamiento
Caracas, Venezuela
kjaffe@usb.ve

ABSTRACT
We propose an agent-based model to explore the joint effect of spatial distribution and the direction information transmission over cooperation’s maintenance. Particularly, we study two information transmission modes: Horizontal (H) and Vertical (V) over five spatial structures: grids 1D and 2D, Random Graphs, Small World Graphs, and Scale Free Networks. Our Results show that cooperation’s dynamics for Vertical and Horizontal transmission are completely different. The effect over cooperation dynamics of Horizontal Transmission is not affected by the spatial distribution, while Vertical Transmission’s effect is altered by spatiality. Particularly, cooperation dynamics are more sensible to Horizontal Transmission in Small World Graphs. Finally, looking at different Horizontal Transmission rates we found that for bigger rates the fewer cooperators survive.

Categories and Subject Descriptors
I.6.3 [Computing Methodologies]: Simulation, Modeling, and Visualization—Applications; J.4 [Computer Applications]: Social and Behavioral Sciences

General Terms
Design, Experimentation

Keywords
cooperation, selfish herd, information transmission, spatial effects, complex networks

1. INTRODUCTION
Biologists, economists, computer scientists and physicists have all worked to further our understanding of human and animal cooperation. Yet different premises underlay these efforts. The main difference among them is the assumption that social behavior arrived through biological evolution among animals, and that culture and rational decision-making is a principal driver of the evolution of cooperation and sociality among humans [19]. Human cooperation seems to be molded by both, cultural and biological forces [11].

There exist important differences between the dynamics of cultural evolution [19] and biological evolution [16]. Although both processes are often mixed up and lumped together when studying the evolution of cooperation, as done in [17]. One important feature differentiating systems driven by biological (BE) and cultural evolution (CE) is the direction of information’s transmission. The transmission of information in BE is vertical (heredity), and that in CE is horizontal (imitation of behavior). This feature affects the pattern and the speed of information transmission, and is sufficient to explain important differences in the dynamics between both types of evolution [10].

Several mechanisms have been proposed to explain the emergence and sustenance of cooperation in biological terms. Hamilton [7] explains cooperation between relatives through “kin selection”; in which donor and recipient of a cooperative action are genetic relatives. Between the mechanisms that have been proposed to explain cooperation between unrelated individuals we have: Direct reciprocity [2, 21], indirect reciprocity [15], altruistic punishment [6] and direct economics forces favoring cooperative groups [12].

The study of the effects of spatiality over cooperation was introduced by Nowak and May [18]. They showed how cooperation could emerge in a population of strategies without memory when individual’s relations conform a spatial structure. After Nowak and May’s work, cooperation by individuals occupying spatial positions in lattices or networks that interact with their neighbors has been studied for the prisoner dilemma by several authors They showed that structured populations help cooperation to evolve and maintain under certain conditions, but can hamper cooperation in others [9, 13, 20].

In this work we want to explore the effects of spatiality and the direction of information transmission over cooperation dynamics. To do so, we modify a one-dimensional spatial model proposed by Cipriani and Jaffe [4] in order to incorporate different spatial structures in the form of grids and complex networks. Our model is based on the well-known “selfish herd” concept [8] and assume that cultural and biological dynamics are driven by natural selection of the phenotypes. This model allows us to study the differences between the dynamics of cooperative, group-forming individuals subject to a selective pressure (predation).
2. THE MODEL

We construct an agent-based model for the study of cooperation dynamics based on Hamilton’s “selfish herd” [8]. The model simulates a population of interacting individuals with different social roles and different information transmission directions in environments over different spatial structures. In this formulation, the “selfish herd” is implemented by means of the importance of group formation. In particular, group formation provides protection against predation.

Spatial structures (that represent spatial relations or contact between individuals) are modeled using graphs. The vertexes of these graphs can be occupied by individuals of any species or be empty. The phenotype of an individual determines its role: cooperators and non-cooperators. The neighbors of an individual in the graph form the group of this individual. These graphs are initially empty and are created at the beginning of the simulations, through the createWorld() function, as shown in Algorithm 1. Their structures remain fixed throughout the simulation execution.

Algorithm 1 Main simulation cycle pseudocode
1: createWorld(worldSize)
2: populateWorld()
3: for t = 0 to numIterations do
4: for each agent do
5: agentStep()
6: end for
7: repopulateWorld()
8: end for

Initial population is created using populateWorld(). This function fills each vertex with an agent, and the probability for each agent to belong to each specie, cooperators or non-cooperators is given by the parameters p_{nCo,Ini} \& p_{nCo,Ini} respectively. The procedure agentStep(), see Algorithm 2, implements the main activities of the agents: horizontal information transmission (in the form of imitation), and selective pressures (in the form of predation). We will detail this procedure on the next paragraphs. Re-population in the repopulateWorld() procedure, defines if Vertical Transmission is enabled. It is done by filling empty world’s spaces (graph’s vertexes). With Vertical Transmission current proportions of individuals’ kind are used, otherwise the initial proportions of each kind of individuals are used.

Algorithm 2 agentStep pseudocode
1: neigh ← getMyNeighbors()
2: nNeighbors ← count(neigh)
3: nNeighborCooperators ← countCooperators(neigh)
4: if CT then
5: applyMajorityRule()
6: end if
7: dead ← predare(nNeighborCooperators)
8: if not dead then
9: naturalMortality()
10: end if

Now we will describe the agentStep(), Algorithm 2 procedure in more detail. The function getMyNeighbors() obtains the direct neighbors of the agent, then we count the cooperators. When a cooperator agent is inside a group of cooperators (two or more of their neighbors are cooperators) it receive a protection against predation, i.e., its predation probability is set to pCo, while the predation probability for “isolated” cooperator agents (pCo0n) and no-cooperators agents (pNC0) are bigger. The majority rule is implemented here to simulate the Horizontal Information Transmission (H). It assumes that individuals had a given probability pT of imitating the behavior of their neighbors. The majority rule used in our model uses the simple majority concept. If strictly more than half of the neighbors of an agent are of a different kind, this agent changes its behavior (cooperate or not) with probability pT. Then, if the agent is still alive we checked if it should not be dead by natural reasons, as aging. This check is done for all kinds of agents but the mortalityRate could be different between cooperators and non-cooperators. This difference allows establishing the “cooperation cost”, by making the mortalityRate of non-cooperators zero, and the giving to cooperators a mortalityRate equals to the desired cooperation cost.

3. EXPERIMENTS
We implemented the proposed model in C++. This implementation allows environment for populations, in the form of complex networks, implemented as bidirectional graphs. Simulations were done over populations of 10^4 individuals during 10^2 iterations.

At the beginning of simulations the graphs’ vertexes were populated by cooperators and non-cooperator, using a probability of 0.5 for each. For non-cooperators and alone co-operators the rates for predation were pNC0 = 0.8 and pCo0 = 0.8. For cooperators in groups the predation rate was pGCo = 0.2. The mortality rate, used modeling the cost of cooperation was 0 for non-cooperators and variable (into each experiment series) for cooperators. For all simulations the “fitness differential” was 0.6. The “Fitness differential” is the difference between the predation rate of isolated individuals and that for cooperators being part of a group of cooperators.

For each one of the spatial structures studied (Grids 1D and 2D, Random Graphs[5], Small-World Networks[22] and Scale Free Networks[3]) we considered four scenarios: one scenario for vertical information transmission and three for horizontal information transmission, varying cultural transmission rates (pT \in \{0,0.5,1\}). In all scenarios production of new agents for was uniform (50/50), and the rate pT determined the probability an agent would imitate the behavior (cooperate or not) of the majority of its neighbors.

Our experiments consisted in 4 series of simulations, corresponding to the described scenarios, over each specific spatial structure. In each series (21 simulations) we varied the cost of cooperation (mortality rate of cooperators) in steps of 0.05, to cover the interval between 0 and 1. Each experiment was run 20 times to get the average of data.

For each network we set its parameters to get the same mean degree. We choose mean degree 4 in order to make a “fair” comparison between the studied complex networks with 2D grids. These parameters are shown each network’s legend (Fig.2(a), Fig.2(b), Fig.2(c)).

Each network structure possess a set of statistical properties that allow explain their behavior. Even though significant properties are still been developed, the most studied are: the mean geodesic path, the clustering coefficient, the degree distribution, the network resilience, the mixing
patterns, the degree correlations and the community structure[14]. In Table 1 we present the values of some of these properties for studied networks. Degree related values were taken from our networks, while the average path length for complex networks was calculated using equations from [1]. We also checked that degree distributions correspond to theoretical predictions.

<table>
<thead>
<tr>
<th>Graph</th>
<th>mean degree</th>
<th>degree SD</th>
<th>average path length</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D Grid</td>
<td>4</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>Random Graph</td>
<td>3.99</td>
<td>1.99</td>
<td>6.64</td>
</tr>
<tr>
<td>Small World Graph</td>
<td>4</td>
<td>0</td>
<td>460.517</td>
</tr>
<tr>
<td>Scale Free Network</td>
<td>3.99</td>
<td>6.88</td>
<td>28.198</td>
</tr>
</tbody>
</table>

Table 1: Grids and network properties’ values.

4. RESULTS

The results of our experiments are shown in Figure 1 and Figure 2, where each sub-figure summarizes the results from simulations of a particular spatial distribution: grid or complex network structure: Grid 1D (Fig.1(a)), Grid 2D (Fig.1(b)), Random Graphs (Fig.2(a)), Small World Networks (Fig. 2(b)) and Scale Free Networks (figure 2(c)). These figures show the final proportion of cooperators for each scenario under various cooperation costs.

For Vertical Information Transmission cooperators invade the whole population or are extinguished, the point for extinction depends on the mean degree of the spatial structure. Under Horizontal Information Transmission in all the spatial structures and all the scenarios the proportion of cooperators decreases monotonically as cooperation cost (cc) increments. These basic morphologies of the resulting dynamics are not affected by the spatial structures.

Looking deeper at Horizontal Information Transmission, for Grids 1D and 2D (Fig. 1, used as control spatial structures, there are small differences between studied Horizontal Transmission rates. Is interesting to note that when pT = 0, the curves show no differences between all the spatial structures studied. On the contrary, larger values of pT (pT = 0.5 and pT = 1) provide larger reductions of cooperators. This effect, present in all networks, is reduced by Scale Free Networks and increased by Small World Networks.

5. DISCUSSION AND RESEARCH PLAN

The results show that spatial distributions affect the influence of Horizontal Information Transmission on cooperation dynamics. On the contrary, the effect of Vertical Information Transmission is not affected by spatiality. Under Vertical Information Transmission cooperators take the whole population or are extinguished. On the other hand, Horizontal Information Transmission always allows the survival of a fraction of cooperators inversely proportional to the cost of cooperation. It strikes us that horizontal transmission of information has a negative effect on the amount of cooperators that survive the evolutionary dynamics. This result is due to the fact that the cooperative strategy is more susceptible to invasion by the opposite strategy than the non-cooperative one. A lack of communication or horizontal transmission of information favors groups of cooperators, benefiting from each other’s neighborhood, who are then less likely to be disrupted by non-cooperators. The largest effect was seen in Small World Graphs, which happen to be the networks with the lowest variance in the degree of connectivity of the nodes. The effect on the evolutionary dynamics of Random Graphs and Scale Free Networks is also inverse to their variance on the degree of connectivity; but the average path length, one of the more important property of the network does not appear to affect the dynamics. As part of our future work we will perform an in-depth analysis of the networks properties in order to achieve a better understanding of the effect of each spatial structure over cooperation dynamics. We also are planning to study variable Horizontal Information Transmission rates, based on the proportion of cooperators neighbors. It is also of our interest to incorporate free-riders into the system.

![Figure 1: The effect of horizontal information transmission is stabilizing cooperation on grids 1D and 2D. Final fraction of cooperators in simulations with different costs for cooperation (x axis).](image-url)
Figure 2: The effect of horizontal information transmission is stabilizing cooperation on complex networks spatial structures. Final fraction of cooperators in simulations with different costs for cooperation (x axis).

6. REFERENCES