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A game-theory modeling approach to fitness and trust dynamics in biomedical research social networks

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Abstract Background: In an ideal world, access to research resources should be fair and equitative according to the proposals relevance and the researcher's academic record. We know that this is not necessarily so, specially in places where access to some resources, e.g., biological samples, is not regulated. Other factors may come into play like social connections, political power or prestige. In this work we explore the distribution of fitness and trust in a biomedical researchers collaboration network when playing a variation of an iterative prisoner's dilemma in which agents are compromised in either defecting and increasing their individual fitness or cooperating and increase mutual fitness with their neighbors. **Methods:** Fitness is a property of the each agent and trust is a property of the link between two agents. According to a pay-off matrix and a mutual trust A_{ij} matrix, we get a measure of naïvité or confidence for each node. If the agents' confidence is below certain value then the agent will act suspiciously and will defect, othewise it will cooperate. We tested our simulation on an Erdös-Renyí, a Watts-Strogatz small-world and Barabási-Albert topologies, as well as on a real biomedical research network. Agents behavior is updated in a synchronous manner. **Results:** All networks find a point of equilibrium before the 50^{th} iteration. Different topologies display different fitness and trust distribution. Fitness in an Erdös-Renyí netwok follows a normal distribution and trust is bimodal. For a Watts-Strogatz, small world networks, both fitness and trust distributions are strongly skewed to the right. Barabási-Albert topology has a heavy left-skewed distribution (resembling to a power-law) and trust is bimodal. The biomedical researchers network has

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fitness distribution as in a Barabási-Albert, but trust is distributed as in a Watts-Strogatz, small world topology. **Discussion:** 1) The distribution of fitness in the researchers network suggests that there are mechanisms governing the network that produces an asymetric access to resources. 2) Nevetheless, trust variables behaves as in the small-world model which might reflect some sort of subordination among researchers by which they are obliged to cooperate. 3) The range in the threshold that regulates the stringency to cooperate or defect according to the agent's naïvité is small, suggesting that there is a region in which a phase transition takes place from a population full of defectors to a population of cooperators 4) Finally, we would like to propose that this sort of work may help to make visible the need to develop science policies to promote a better, small world-like, fair fitness distribution.

Keywords Game theory · Trust · Models · Biomedical research community · Social Networks

1 Introduction

Collaboration has become a corner stone in scientific research today. Though physics has a long history and experience in collaborative projects, biology has recently become an evermore collaborative discipline[1]. Biology has interesting record in such matters because scientific collaboration has been perceived differently depending on the branch of biology one is taking about. As molecular biology has traditionally been a research activity of small laboratories[2, 3]. On the extreme, there is natural history exchanging data and samples since the $XVII^{th}$ century[4, 5].

Despite the differences in culture and practices, the Human Genome Project made collaboration a central feature of biology. Now a day it is widely aknowledge that collaboration takes many forms, from biological samples and biobanking to international groups in charge of helping the bio-research communities to harmonize and share their data.

As has been pointed by others, social research on scientific collaboration is mostly about physics and space research. Collaboration in biology has been studied to a lesser degree. The majority of work done on the subject has explored the quantiative aspects of it[6]

2 Biomedical research: CONACyT and FOSISS

CONACyT (Council of Science and Technology) is the Mexican government entity in charge of promoting the development of science and technology. It is also in charge of creating the country's scientific policies. In a way, CONACyT is equivalent to the National Science Foundation of the United States.

Among CONACyT's functions it is to develop science and technology policies according to national needs and demands, to offer assessorship to the different instances of the government on scientific and technological topics, to promote the creation of research networks among the scientific community, grant scholarships for masters and doctoral studies, and it also manages different trusts intended to fund individuals and groups for scientific and technological research.

In the year 2002 CONACyT, along with other government agencies and entities have created sectorial funds or *Fondos Sectoriales*. Sectorial funds are trusts for scientific and technological research. The objective of such funds is to cover and equally promote the research capacities of different areas such as energy, agriculture, or technological innovation by means of the generation of human resources and helping research groups to consolidate. It is expected that the knowledge generated under the sponsorship of *Fondos Sectoriales* to be the product of applied research that attends national public needs, and promotes economic growth.

FOSISS or Sectorial Fund for Health and Social Security Research (*Fondo Sectorial en Investigación en Salud y Seguridad Social*) is among such funds. FOSISS is constituted by CONACyT, SSA, IMSS and ISSSTE,[1] being all of them the major public health providers and research institutions in the country. Every year CONACyT opens a call for funds constrained to a set the health areas previously defined by a group of experts. Elegibility is open to the public and private health research sectors, nevertheless, most applicants are public universities and research institutions.

3 Methodology

In this work we developed a model in order to have a better understanding the distribution of fitness and trust in a biomedical researchers collaboration under certain social constrictions or topological properties of real collaborative networks of biomedical research.

Our model is based on the iterative version of the prisoner's dilemma (PD) instantiated on networks. Implementing games on networks is not new and is an active area of research aimed to understand the evolution of cooperation in networks populated by selfish agents [7,8,9]. In many network models on which some of game theory games are simulated, agents decision to cooperate or defect depends on a specific strategy, as the well known *tit-for-tat* [10,11]. In some other cases, agents can modify the weight of the interactions with their

[1] SSA is the acronym for Secretariat of Health *Secretaría de Salud*; IMSS is the acronym for Social Security Mexican Institute (*Instituto Mexicano del Seguro Social*); ISSSTE stands for Institute for Social Security and Services for State Workers (*Instituto de Seguridad y Servicios Sociales de los Trabajadores del Estado*)

neighbors [12]. From a different perspective others have explored the effect of different topologies on the emergence of cooperation [13,14]. In our case, agents decision to cooperate or defect is a probabilistic outcome that depends on the agent's confidence. Confidence, as it turns out, depends on how positive the agent's gains and relations towards its neighbors have been in the past and we study the behavior of the system under different topologies, including a real-world network.

In the model that we developed, agents are embedded in a network with varying number of neighbors. Following the traditional PD game, the strategy chosen by an agent and the strategy chosen by its neighbors will produce a pay-off. Pay-off follows the rule: $T > R > P > S$. T is for temptation to defect. It is the highest pay-off and it takes place when the player defects and the other cooperates. R is for reward for when both players cooperate. P is the punishment for when both players defect. And S is for suckers pay-off. Fitness is a property of agents in which pay-off is accumulated.

Prisoner's Dilemma fitness pay-off matrix

	Cooperate	**Defect**
Cooperate	R, R	S, T
Defect	T, S	P, P

Trust is a property of the link between two agents and it is updated according to a mutual trust A_{ij} matrix. In the trust matrix, the highest value goes to an edge when both agents cooperate, getting an R for reward, if one of them defects, trust is negatively affected or P for the trust being punished. If both agents defect, trust value doesn't change, which in a sense, it means that agents didn't interact or that the interaction gets nullified N.

Trust pay-off matrix

	Cooperate	**Defect**
Cooperate	R	P
Defect	P	N

After each game, the agent adds-up fitness (w), which is the sum of the pay-offs following the PD matrix. The agent also adds-up the amount of trust (t_{ji}) that shares with its neighbors. We measure global fitness and trust for the whole network. Global fitness is the sum of all individual fitness and trust is the sum of every pair of agents links trust. normalized. In order for the agent to choose to cooperate or defect, it is assigned a degree of naïvité. Naïvité is calculated as the sum of the agent's normalized averages of fitness and trust over the number of the agent's neighbors.

Naïvité $= \langle w \rangle + \langle t_{ji} \rangle$

If the agents' naïvité is below certain global confidence threshold then the agent will act suspiciously and will defect, othewise it will cooperate. We tested our simulation on an Erdös-Renyí, a Watts-Strogatz small-world and Barabási-Albert topologies, as well as on a real biomedical research network. Agents naïvité or confidence, state, fitness and edge's trust is updated in a synchronous manner.

3.1 Implementation of the model in different topologies

3.1.1 Erdös-Rényi

3.1.2 Small-World

3.1.3 Barbási-Albert

3.1.4 Biomedical research community network

The biomedical research network on which we are running our model was generated with data from collaborative projects. Our data was obtained from CONACyT and includes information for twelve years of *FOSISS* grants. Data included names of Principal Investigators, collaborators, research topics, etc. The network we are using here has researchers as nodes and edges represent the connection of two scientists when they participate in the same project. Edges are also weighted according to the number of projects shared by the pair of scientists. The complete network summed-up a total of 145 components or sub-networks, but we are running the model on the only giant component made-up of 4122 researchers, and 23391 edges.

The giant component is a well integrated network, with a clustering coefficient $\langle C \rangle = 0.870$, an average shortest path length of $\langle l \rangle = 5.493$ and a density of $p = 0.003$. Such properties recall a small-world topology [15], and a great deal of self-organization when compared to a random network with the same density and number of nodes.[2] The network centralization is 0.023, since there are no visible researchers that play as hubs in the network. Nevertheless the network heterogeneity is 0.873, which means that the network is highly hierarchical. When the degree distribution is analyzed, degree deceases as a power-law with an exponent of 1.7, similar to other social networks described as scale-free topology networks [16]. Finally, the number of neighbors of each node is 11.39.

[2] Using networkx in Python we created a null model to test such properties of our network on a random graph. The results were the expected with a $\langle C \rangle = 0.00279$, and a $\langle l \rangle = 3.6$ [15].

4 Results

5 Discussion

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