Selfish Rewiring for Cooperation

Emergent link-based incentives in a peer-to-peer simulation

Overview

DELIS

Dynamically Evolving, Large-scale Information Systems

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Abstract

In open peer-to-peer networks how can the negative effects of selfish (egotistical) behavior be discouraged? This kind of problem is well studied in social science and is called the "tragedy of the commons". We adapt a novel mechanism, called "Tags", from social science research, applying it to a simulated P2P network. Even when the nodes behave individually selfishly, "emergent incentives" lead to cooperation to achieve collective goals.

The process works through a dynamic system of copying and rewiring of node behaviors and links. Nodes attempt to maximize their own utility by locating better "network neighborhoods" to move to.

- Periodically nodes compare their utility with another randomly chosen node
- The lower scoring node copies the links and behavior of the higher scoring node (replication)
- With a low probability, nodes change their links and behavior randomly (mutation)

These minimal assumptions are enough to produce high-levels of cooperation between nodes because selfish "bad-guys" are effectively ostracized over time – the "good guys" move away to better neighborhoods.

The Prisoner's Dilemma

The Prisoner's Dilemma game is a way to formalize, minimally, the contradiction between individual and collective self-interest. It has been used by Social Scientists (Economics, Political Scientists) as a basis for testing rigorously, minimal conditions required for cooperation in social groups. Figure 1 shows a "payoff matrix" from the game. There are two players and each player chooses one of two moves (C or D). The matrix shows the scores (or payoffs) that are given to each player based on the moves they make. Given the constraints on the payoffs (T, R, P, S) and that neither player can know in advance how the other player will behave - the dilemma is this: any player selecting D will never do worse than the other player and may do much better – so it's individually rational to select this, however, if both act "rationally" in this way, they both do worse – by both getting the P (Punishment) payoff. The D move is the "Nash Equilibrium" of classical game theory.

Given: $T > R > P > S$ and $2R > T + S$

Player 2 \ Player 1	C	D
C	R, R	S, T
D	T, S	P, P

Fig. 1. The payoff matrix for the Prisoner's Dilemma game. The values T, R, P and S must conform to the constraints shown.

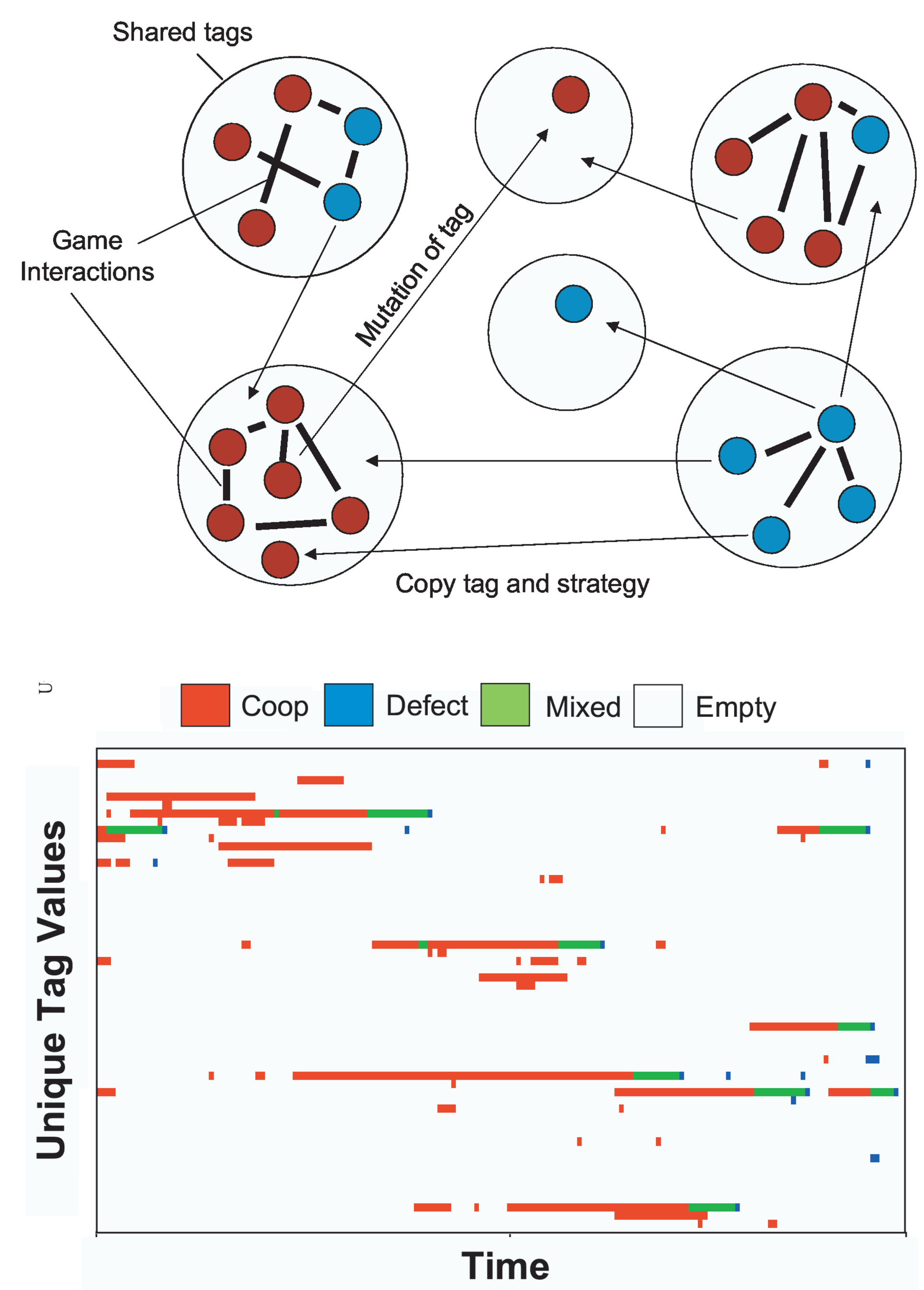

Fig. 2. A schematic of tag evolution (above) and output from a non-network simulation model (below).

Tags

The "tag" mechanism, recently, applied in social science simulations is an evolutionary "group selection" method that promotes cooperation between selfish agents. They bias game interaction towards those with similar tags. These represent social cues like style of dress, accent or "old school ties". A dynamical non-equilibrium process – in which groups form, dissipate and reform – is produced that is highly scalable and robust to noise (see figure 2).

Evolution on the Network

By reinterpreting an evolutionary process as a network rewiring process, we can translate the tag model into a network model – A simulated P2P system in which neighbor nodes play the PD. This translation was done to determine, empirically through simulation, if the same process could be produced in a network topology – previous tag models had no topology (mean field mixing). Figure 3 shows an example of the replication and mutation process as translated into rewiring rules. This evolutionary rewiring algorithm (ERA) produced a highly dynamic network in which cooperation was high – the results appeared scalable, we tested networks of up to 120,000 nodes.

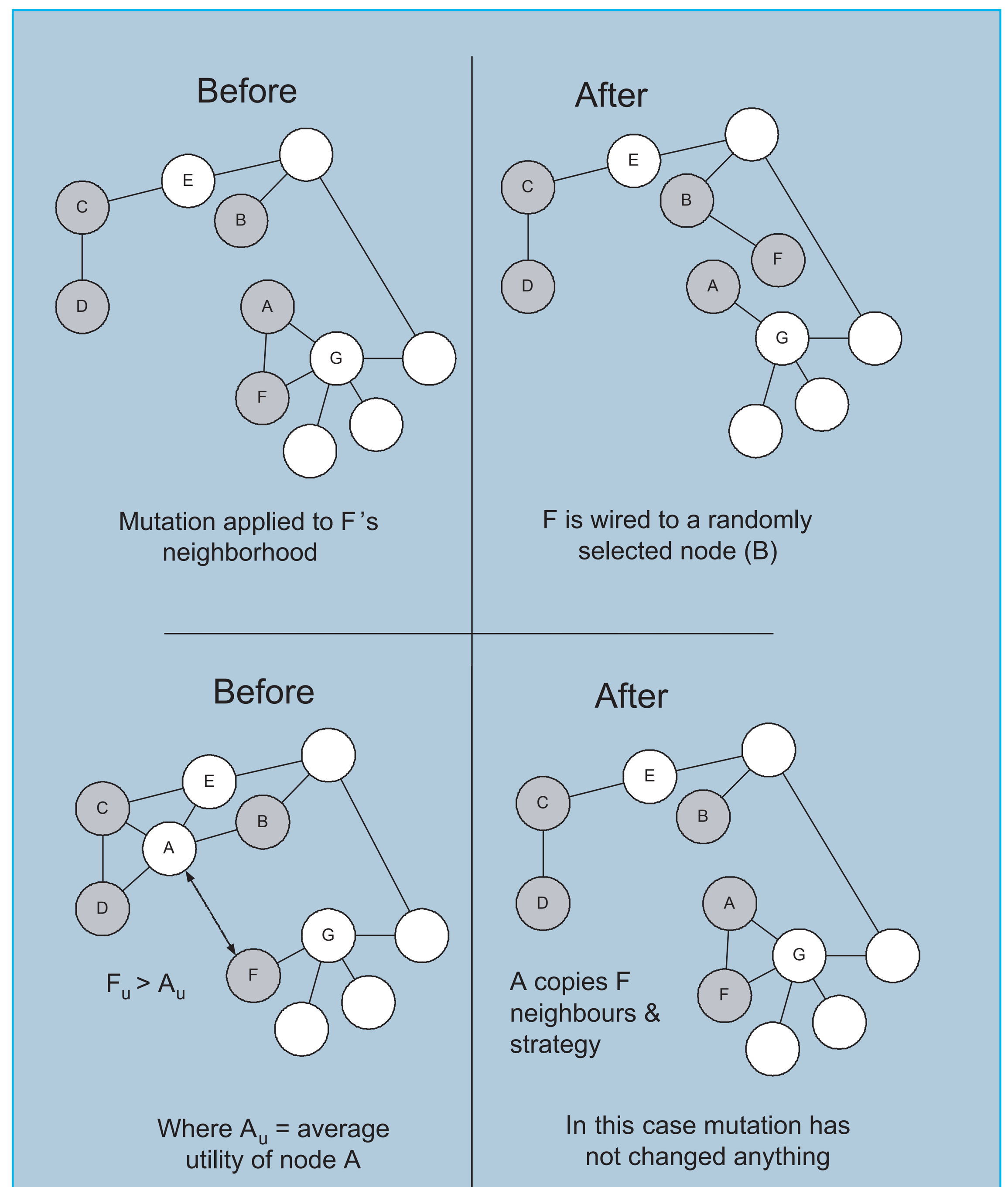

Fig. 3. Examples of the way nodes "rewire" themselves in the network based on utility.

File sharing Scenario

In order to test that the cooperation produced in the PD game could be translated into cooperation in a more practical task we applied the same algorithm to a file-sharing scenario. Instead of "abstract utility", we used the number of query "hits" a node received over a time period. We found that the ERA algorithm operated to control the selfishness of the nodes and promote cooperation – by suppressing nodes spamming the network selfishly with their own queries. Figure 4 showns simulation results over a number of network sizes.

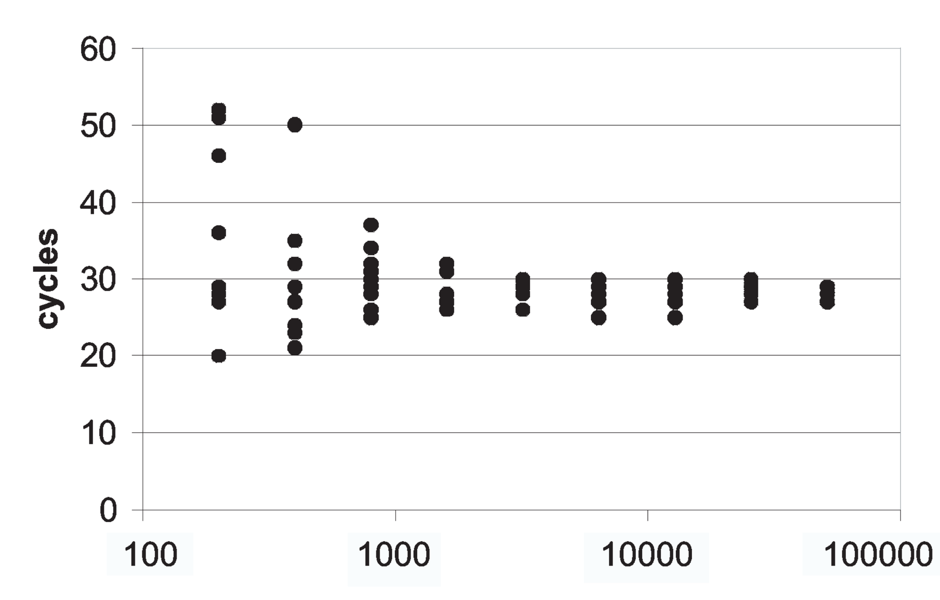

Fig. 4. Results of several simulation runs for different network sizes. Each point shows the number of cycles before high cooperation is attainted.

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