Social Networking and Game Theory to foster Cooperation*

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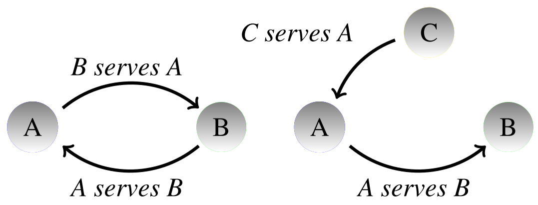
Abstract

Reputation management systems have been proven in the past to be a valuable tool to foster cooperation in distributed systems, as they rely on the nodes' active participation to sustain the availability of the resources and scalability. In this paper, we exploit ideas from Game Theory to propose a game theoretical framework to model the interactions of rational and selfish nodes in distributed systems. Our approach differs from previous works in the field as we introduce reputation in the definition of the utility function along with a punishment factor for nodes cooperating with untrustworthy entities.



(a) Direct Reciprocity (b) Indirect Reciprocity

Figure 1. In *direct reciprocity* **(a) node A serves node B. In case of** *indirect reciprociy* **(b) node A serves node B to build its reputation so that in the future it can be served by node C.**

1 Introduction

Peer-to-peer systems are characterized by heterogeneous components sharing a common interest. These components, which might be under different administrative domains, interact to achieve their specific goals and to sustain the scalability of the system. However, the difficulty in establishing direct relationships complicates the measurement of nodes' trustworthiness.

Thus, the participation of the nodes and the quality of the communication cannot be granted in a systems formed by "strangers". If the survivability of peer-to-peer networks relies on the nodes' willingness to fill their obligations, the system might not function properly: non-cooperative or selfish behaviour will be privileged and predominant. This occurs because individual rational nodes are incentivized at maximizing their own use of the resource while the costs of the service are shared between all those to whom the service is available. As a result of this "tragedy of the commons" [6], selfish nodes do not share their resources if they cannot increase their *utility*.

In un-managed and fully distributed systems where there is no authority to force nodes to follow an altruistic behaviour (where nodes cooperate without reward), incentive mechanisms leading to "reciprocal altruisms" are required to foster cooperation among nodes. A viable solution is found in reputation management systems to measure trustworthiness in a collaboration-based network.

In social and economic science numerous works map entities interactions in virtual communities and discuss the impact of reciprocate behaviour of the nodes in their interaction [8, 3]. Cooperation upon previous successful experience (see Figure 1 (a)) is applicable if the same nodes interact frequently during their lifetime. However, peer-to-peer systems or large distributed communities face the problem of nodes that sporadically meet. Thus, this scheme results to be not effective in this context due to the limited number of direct interactions. Another approach is based on indirect collaboration of nodes as shown in Figure 1 (b). This mechanism implies that indirect reciprocity relationships can be established if the transactions are monitored and the result of this observation is shared among the nodes [8].

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The application of the concept of indirect reciprocity leads to the definition of reputation management schemes. They monitor participants' behaviour in all transactions in order to compute the nodes' trustworthiness. Then, this information is used to build knowledge of the behaviour of the nodes to estimate the expected quality of the nodes in providing resources.

Many reputation schemes have been proposed in the literature and have been deployed for different contexts ranging from peer-to-peer or content distribution networks [4, 5] to mobile ad-hoc networks [7]. But, the question how *building* reputation is important for a node's future interactions is not clearly addressed. Furthermore, if we consider rational nodes, in the sense that they strategize to increases their expected utility from the system, there is no clear understanding of the role of reputation in selecting a specific action/strategy. In most cases nodes might want to collaborate to keep their trust value above a certain threshold that allows them to consume system resources at the minimum "price". In our opinion reputation systems are at the boundary between social and economic sciences as well as evolutionary biology and computer science.

For this reason a closer analysis of the adoption of reputation management systems from an interdisciplinary perspective is needed. This is where our approach comes into play. In our formalization of the system properties, we discuss the evolution of the system under the enforcement of a reputation management scheme. In this paper, we focus on the issue of reputation and trust building in a decentralized system. Moreover, we derive conclusions from the adoption of specific economic theories to model peer-to-peer systems. Specifically, we discuss how cooperation can be enforced in an autonomous distributed system formed by selfish agents and we focus the attention on reputation with respect to its definition of "future revenue".

2 Reputation scheme definition

The specific objective of a reputation management system is to facilitate nodes to decide whom to trust for providing to the requesting node the best quality of services or resources. To serve this objective a reputation management system should perform three distinct functions: 1) collection, 2) aggregation and 3) dissemination of trust information. Moreover, the reputation management system should *motivate* nodes to expose cooperative behaviour and discourage malicious nodes to take an active role in the network.

Incentives and punishment are two complementary functions that deal with rational nodes and malicious nodes respectively.

In a previous work [4], we focus on the definition of a reputation management system to evaluate global reputation values for peers. Reputation values are calculated on the basis of first-hand opinions of transactions provided by the participants ("*collection*"). These opinions are weighted according to the credibility (or second-order reputation, i.e. a peer trustworthiness in the reputation system) of the reporting peer and the attached quality value which reduces the impact of an opinion in the reputation function ("*aggregation*"). The "*dissemination*" of the reputation values is managed in a distributed fashion by using multiple trust managers for each individual peer, which form the peer global trust and send it upon request from other peers. Herein, we concentrate on incentives and punishment and propose a trust economic model based on Game Theory for peer-to-peer systems.

3 Game theoretic approach

We consider that 1) the system population consists of a fix number of nodes (N) with the same capabilities 2) nodes do not participate in a collusion and 3) the identities of the nodes are fixed during the game. We assume asymmetric interactions between two nodes having different roles, service provider and service consumer. The serving node has to decide on the service provision and the receiving should decide whether to reward the action of the node. Nodes are defined to be rational and strategic: at each interaction they can choose the action (cooperation or defection) which will influence the outcome of the system. This results in a *non-cooperative* game, as nodes want to maximize their utility. The game is played in multiple stages and the strategy (set of actions) chosen by the nodes can either be fixed at the beginning of the game or evolve during the game.

We further assume that at the end of each period of time, the results of the interaction are made available to the system population and the utility functions of the nodes are updated. The utility of a node depends on the resources or services it can access and on the cost to provide or obtain them. Thus, it is not only the result of its decisions but it depends on the actions the other nodes in the system take. At each node is also associated a reputation value which is updated after every transaction to track nodes behaviour.

The problem can be formulated as follows: how does one combine reputation values and utility derived from service exchange in a way such that nodes are willing to cooperate and they are punished if they help selfish nodes? Naïve cooperation towards every peer increases the reputation value of the collaborating node but it also incentives free-riding. Therefore, incentive and punishment must be balanced to avoid free-riding in the system. These two concepts are reflected in the definition of the strategy that the node follows during the game.

Bravo et al. [2] discuss general condition for cooperation. Their model shows that in the sequential Prisoner's Dilemma (also known as Trust Game), when two players do not move simultaneously, cooperation is possible if high reputation values of the nodes can be built. However, it is required that either the reputation information is public and consistent or that players can exploit direct experience to support indirect reciprocity in repeated interactions.

4 Reputation Game strategies and nodes interaction

The general findings discussed in the previous section and presented in [2] motivate the definition of reputation schemes that encourage nodes to build high reputation values. However, in a peer-to-peer system cooperative nodes can frequently interact with selfish peers and the effect of these interactions should be considered for the stability of the system.

Let assume that provider and consumer nodes have two available actions (collaborate or defect) at each stage of the game: collaborate (provide the service) or defect (ignore the request) for the provider and collaborate (reward) or defect (do not reward) for the consumer. Then, if a node can play the two roles in different stages, the reputation built when acting as provider can be spent to obtain resources from other nodes. This leads to a discriminant strategy for the provider when the behaviour is a function of the consumer's reputation [2].

Therefore, requests for services are screened by means of the reputation value. In order to introduce a simple resource access control, we envision two possibilities: 1) define a threshold above which nodes can access resources (discriminant strategy); 2) define a penalty for nodes that provide services to lower reputation nodes (punishment for collaborating with selfish nodes).

The first case would cause side-effects to our model as nodes that have a low reputation value given by past defection and that are not served, will abandon the system. This would be a satisfactory consequence of the application of a reputation management system; unfortunately, the threshold must be chosen carefully to avoid honest nodes to be out of the system. Moreover, players will choose their strategy in such a way that they will defect in some interactions if their new reputation value does not go below the threshold. As a consequence the system will favour defection at some time and cooperation will not be always achieved.

At first sight, the second case penalizes nodes that cooperate with low reputation opponents. This is true only if we consider a single stage of the game and that fostering cooperation is the *only* desirable property of the system. Assuming that there is no punishment in place, serving nodes will choose a strategy that forces them to always cooperate (ALL-C) so that they can increase their reputation value. However, the earned reputation cannot give any advantage for future interactions as ALL-C nodes will always serve ignoring the trustworthiness of the nodes. Thus, nodes will adapt their strategies and defection will evolve as a norm in the system. Axelrod [1] provides a clear framework on the evolution of strategies in the iterated Prisoner's Dilemma.

Therefore, we proceed to investigate the latter solution as it can lead to the evolution of cooperation. For these reasons we define a cost function for the provider nodes which includes a penalty that is inversely proportional to the reputation of the consumer node. During an interaction a node can compute its utility, from a transaction, as function of the benefit, costs and reputation values, and take a decision in accordance to its strategy. Obviously, the action will have impact on the global trust of the peer in the network and on its further interactions when the game is played infinitely.

5 Conclusions and future work

In this paper we study reputation management systems and define their applicability in accordance to social and economic science. We propose a game theoretical study for reputation management systems. It is based on a simultaneous game when rational nodes must decide their action based on reputation values, costs and benefit of the transactions. We have shown the feasibility of the approach which will be the basic framework for future work in this direction. Future work also includes aspects related to the reputation management system by considering the feedback mechanism which is fundamental for global trust computing.

References

[1] R. Axelrod. The Evolution of Strategies in the Iterated Prisoner's Dilemma, chapter in*Genetic Algorithms and Simulated Annealing (ed L. Davis)*, pp. 32–41. Pittman, 1987.

[2] G. Bravo and L. Tamburino. The evolution of trust in sequential prisoner's dilemma games. In *Third International Meeting. Complexity 2006*, Aix-en-Provence, France, May 2006.

[3] E. Fehr and S. Gaechter. Fairness and retaliation: The economics of reciprocitys. *Journal of Economic Perspectives*, 14:159–181, 2000.

[4] A. Garg, R. Battiti, and R. Cascella. Reputation management: Experiments on the Robustness of ROCQ. In *Proc. of the 1st International Workshop on Autonomic Communication for Evolvable Next Generation Networks*, Apr. 2005.

[5] A. Garg and R. Cascella. Reputation management for collaborative content distribution. In *Proc. of the 1st International IEEE WoWMoM Workshop on Autonomic Communications and Computing*, pp. 547–552, Taormina, Italy, June 2005.

[6] G. Hardin. The Tragedy of the Commons. *Science*, 162:1243–1248, 1968.

[7] P. Michiardi and R. Molva. Core: a collaborative reputation mechanism to enforce node cooperation in mobile ad hoc networks. In *Proc. of the 6th Joint Working Conference on Communications and Multimedia Security*, pp. 107–121, 2002.

[8] M. Nowak and K. Sigmund. Evolution of indirect reciprocity. *Nature*, 437:1291–1298, October 2005.