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# A formal model based on Game Theory for the analysis of cooperation in distributed service discovery

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ABSTRACT

New systems can be designed, developed, and managed as societies of agents that interact with each other by offering and providing services. These systems can be viewed as complex networks where nodes are bounded rational agents. In order to deal with complex goals, they require cooperation of the other agents to be able to locate the required services. The aim of this paper is formally and empirically analyze under which circumstances cooperation emerges in decentralized search of services. We propose a repeated game model that formalizes the interactions among agents in a search process where agents are free to choose between cooperate or not in the process. Agents make decisions based on the cost of their actions and the expected reward if they participate forwarding queries in a search process that ends successfully. We propose a strategy that is based on random-walks, and we study under what conditions the strategy is a Nash equilibrium. We performed several experiments in order to evaluate the model and the strategy and to analyze which network structures are more appropriate to promote cooperation.



## 1. Introduction

Social computing has emerged as a discipline in different fields such as Economics, Psychology, and Computer Science. Computation can be seen as a social activity rather than as an individual one. New systems are designed, developed, and managed as virtual societies of independent entities or agents that offer services and interact with each other by providing and consuming these services [23]. These systems and applications can be formally represented through formal models from the field of Complex Networks [27]. This area provides a theoretical basis for the development of models that help us to reason about how distributed systems are organized [19]. Complex Network models have been used in different contexts such as social networks (collaboration, music, religious networks), economic networks (trade, tourism, employment networks), Internet (structure and traffic networks), bio-molecular networks, and computer science networks among others [5,26].

In complex systems already mentioned, one of the challenges is the design of efficient search strategies to be able to locate the resources or services required by entities in order to deal with complex goals [2,9,26]. Taking into account autonomy of the entities that participate in the search process, three levels of search decentralization could be considered. We assume that at the

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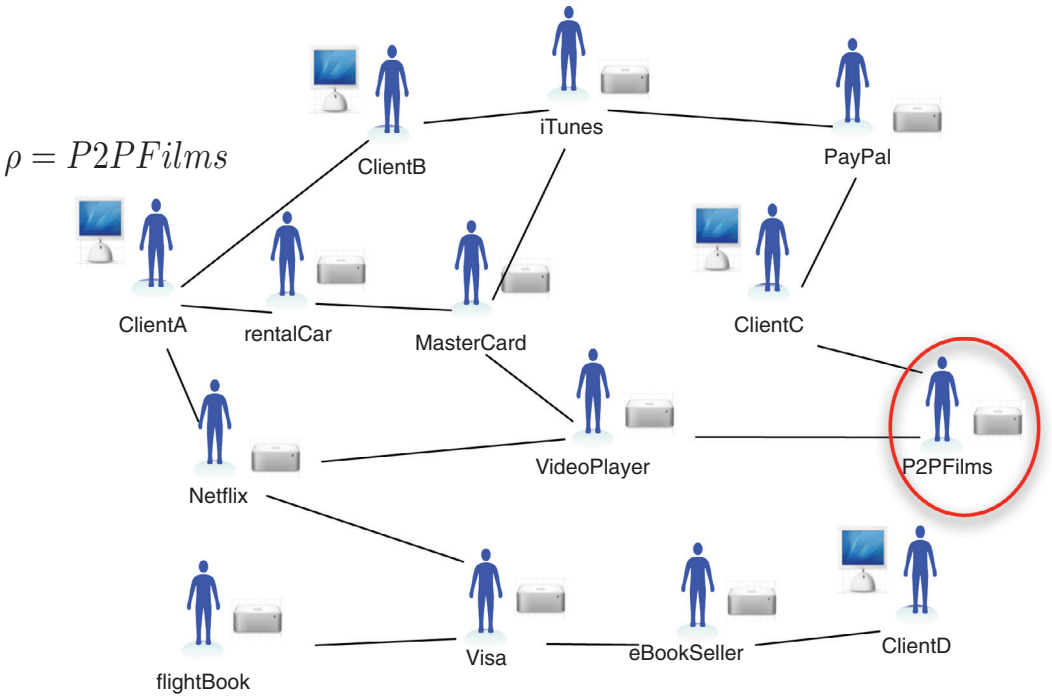


**Fig. 1.** An example of a search scenario.

*first level* the search process is centralized when there is a common protocol that is adopted by all the entities of the system and this protocol dictates the actions that must be followed (i.e., the protocol specifies the entity that starts the process, the sequence of participation of entities, and the target). At the *second level* this protocol can be relaxed. The entities adopt that protocol, and, therefore, they carry out the same set of actions, but the search path (i.e., the sequence of entities that participate in the search process) is not specified. At the *third level*, a decentralized search can be considered when there is a protocol adopted by all the entities that specifies the set of available actions. However, these entities can decide whether or not they are going to follow the protocol. It would not be desirable to impose the same behavior on all the nodes if it takes away their individual choice, (i.e., it would be desirable that all the nodes would follow the protocol willingly). Therefore, we look for a concept of stability within the strategies of the entities of the system. This concept, which comes from Game Theory, is known as Nash equilibrium.

There are several scenarios where efficient decentralized search strategies are required. Some of these scenarios are wireless ad-hoc networks where nodes rely on other nodes to forward their packets in order to reach the destination node, file sharing in P2P systems, streaming applications, discussion boards, on-line auctions, or overlay routing. In this paper, we consider a P2P system as an example of an application scenario. The P2P system is modeled as a multi-agent system. In this scenario, agents act on behalf of users playing the role of a service provider or service consumer (see Fig. 1). Agents that play the role of service consumers should be able to locate services, make contracts agreements, and receive and present results [34]. Agents that play the role of service providers should be able to manage the access to services and ensure that contracts are fulfilled. By considering the system as a network, it is assumed that all the information is distributed among the agents. Since agents only have a local view of the services provided in the network, the collaboration of other agents is required in order to reach the target. For instance, in the scenario presented in Fig. 1, if the agent that acts on behalf of *ClientA* requires a service to see a film without paying, it should interact with the provider agent of the service *P2PFilms*. However, *ClientA* has local knowledge about the available services and their providers (i.e., it only knows about *Netflix* and *rentalCar* services). Therefore, agent *ClientA* starts a search process of a provider agent that performs the task of *P2PFilms* service. To locate the provider, agent *ClientA* needs the collaboration of the rest of the agents in the network. We assume that there is at least one provider agent that is suitable to perform the task.

During a search process, agents can carry out a set of actions: create a task that must be performed by a qualified agent (i.e., start a search process), forward the task to one or several neighbors if they do not know how to solve the task, or perform the task if they can provide the required service. The cooperation of agents forwarding queries plays a critical role in the success of the search process [8]. This action facilitates the location of a resource based on local knowledge. However, in our scenario, this action has an associated cost and agents are free to decide whether or not the forwarding action is profitable to them based on its cost and the expected reward.

In this paper, we propose a model to formally describe the distributed search for services in a network as a game. Specifically, we use the repeated game framework to model both the process that a task follows through the network and the global task-solving process. In the former, each period is a decision stage for the agent who is in possession of the task. In the latter, a project is generated in each period and randomly assigned to an agent in the network.