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Combination of self-organization mechanisms to enhance service discovery in open systems

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ABSTRACT

Decentralized systems have emerged as an alternative to centralized approaches for dealing with dynamic requirements in new business models. These systems should provide mechanisms that contribute to flexibility and facilitate adaptation to changes in the environment. In this paper, we present two self-organization mechanisms for a decentralized service discovery system in order to improve its performance. These mechanisms are based on local actions of agents that only consider local information about queries they forward during the discovery process. The self-organization actions are chosen by each agent individually when the agent considers them to be appropriate. The actions are: remaining in the system, leaving the system, cloning, and changing structural relations with other agents. We have evaluated each self-organization mechanism separately but also the combination of the two as the environmental conditions in the service demand change. The results show that the proposed self-organization mechanisms considerably improve the performance of the service discovery system.

1. Introduction

Nowadays, there is a trend towards large-scale, complex, and highly-dynamic systems in order to deal with new business models and requirements. Peer-to-peer technologies (P2P) [37], Service-Oriented Computing (SOC) [33], or Cloud Computing [7] are considered to be suitable technologies to support these new models where there is a high number of entities offering services that change frequently and look for other entities to collaborate with in order to obtain a resource or to deal with a complex goal.

To facilitate collaboration between entities, systems should provide mechanisms to manage information about which entities or resources are available in the system at a certain moment as well as how to locate them in an efficient way. However, this is not an easy task in open and dynamic environments where there are frequent changes in the available resources and global information is not always available. Under these circumstances, the management and location of available resources become more difficult. The field of Complex Networks has emerged as an alternative to be able to deal with decentralized service management in a flexible and adaptive way [5]. Some of the models proposed in this area provide structures that allow the location of resources in a few steps taking only local information into account. One of the properties present in some of these structures is homophily [44,39,23]. The idea behind this social concept is that individuals tend to interact and establish links with similar individuals along a set of social dimensions. Therefore, in a structure that is based on homophily,

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an individual has a higher probability of being connected to a more similar individual than to a dissimilar one. This criterion creates structures that facilitate the location task and could be considered to be a self-organizing principle for generating searchable structures.

Service discovery systems are deployed in dynamic environments where their components, features, and tasks do not remain constant. These systems are expected to perform well under many circumstances (i.e., when the number of available agents changes, or when the service demand varies with time). Moreover, since there is not a global view of the system in large, open, and distributed systems, this adaptation should be performed in a decentralized way without the supervision of any centralized authority and considering only local knowledge. This ensures that the system is robust under failures.

In this paper, we present a decentralized service management system for service-oriented environments. Specifically, we propose the use of Multi-Agent Systems and Service-Oriented Computing as appropriate paradigms for building these systems [14]. Agents in the proposed system offer their functionality through services and have a collaborative behavior that facilitates the decentralized location of services using only local knowledge. Agents are located in a network where structural relations between agents are based on the self-organizing concept of homophily. The structural relations determine the interactions between the agents, their local knowledge, and, therefore, the performance of the service discovery process. The number of agents and the structural relations between agents do no remain static in open systems. In this way, we present two self-organization mechanisms that are included in the service discovery process in order to facilitate system adaptation when changes in service demand occur. One mechanism focuses on how the relations between agents could be rearranged to improve system performance. The other mechanism considers the adaptation of the agent population according to the service demand. The main advantages of this proposal are that the self-organization of the system is a continuous process that is carried out by each individual agent without central supervision; each agent is able to reason about when it is most appropriate to make a self-organization decision; agents only require local information about the service demand and the utility of their links; and, system dynamics about structural relations and population are taken into account.

The rest of the paper is structured as follows: in Section 2, we present an overview of works that includes distributed search and self-organization strategies in distributed environments. In Section 3, an example of a service discovery scenario is presented. In Section 4, we describe the formalization of our proposal for the self-organization of the decentralized discovery system. In Section 5, the self-organization actions that agents can execute during the service discovery are described. In Section 6, we present a set of experiments to validate the proposed model and the self-organization mechanisms in different scenarios. Finally, in Section 7, conclusions and final remarks are presented.

2. Related work

Large-scale, open, and highly-dynamic systems are populated by entities that have to deal with complex tasks and need services provided by other entities in order to fulfill their goals. Therefore, these systems should provide mechanisms to manage the information about the available services in the system and to determine which entities provide them. Moreover, in order to deal with changes in the requirements or in the environment conditions, these systems should provide self-organization functionalities. *Self-organization* is considered to be the mechanism or the process that enables a system to arrange its organization at run-time, without explicit external commands [13]. Starting from entities that are structured in a sub-optimal organization or that are not organized at all, a self-organizing system is able to form a specific organization to pursue a well-defined goal [24]. The main issue in self-organization is to determine the best mechanism for reorganizing the current structure through the execution of local actions in order to achieve the desirable behavior despite a high degree of uncertainty in the system. Self-organization mechanisms attempt to deal with this task. The inclusion of these mechanisms in distributed systems provides desirable system features such as openness, robustness, flexibility, or scalability [45]. However, the main goal is the improvement of the system utility in dynamic environments. In order to facilitate the integration of self-organization mechanisms, it is desirable for the systems to have three main features: (i) no external control, central authority, or supervisor should guide the adaptation process. The adaptation process should be carried out locally, based on the local interactions of each entity; (ii) the system should be able to evolve; and (iii) the entities of the system should be able to deal with uncertainty in order to make decisions. In this context, researchers have proposed mechanisms that deal with distributed service discovery and self-organization in several ways.

In distributed approaches, the responsibility of resource management relies on a set of specific entities to provide scalability and robustness. In P2P systems, structures based on *super-peers* [36] and *Distributed Hash Tables* (DHT) [40,30] have been proposed. Super-peer approaches have problems when several super-peers fail and other peers that are less qualified must replace them. DHT approaches are able to locate resources in $O(\log n)$. Nevertheless, the maintenance of the indexes when peers join and leave the system affects the performance of the system. Updates imply the interchange of messages among peers; therefore, the system could be in an inconsistent state during a period of time due to outdated references. Furthermore, these mechanisms are not very effective in locating resources with partial information. The accuracy of the search is reduced since the search is based on numeric keys and does not consider semantic information, which allows more flexible and accurate search processes. There are some approaches based on super-peers that deal with this problem introducing semantic information. In these systems, peers with similar content connect to the same super-peer and sophisticated routing strategies based on the metadata schema, attributes and ontologies are used [31].

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