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Managing parallel inquiries in agents' two-sided search

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Abstract

In this paper we address the problem of agents engaged in a distributed costly two-sided search for pairwise partnerships in Multi-Agent Systems (MAS). While traditional two-sided search mechanisms are based on a purely sequential search of all searchers, our mechanism integrates an ability of some of the agents to maintain several search efforts in parallel at each search stage. We show that in many environments the transition to the new mechanism is inevitable since the adoption of the parallel-interactions based search suggests a greater utility for the searching agents. By exploring the appropriate model equations, we present the new dynamics that drive the equilibrium when using such a mechanism in MAS environments. Complementary algorithms are offered, based on the unique equilibria characteristics found, for facilitating the extraction of the agents' strategies. The analysis methodology used supplies a comprehensive solution to a self contained model, and also offers a great value for future work concerning distributed two-sided mechanisms for MAS. Towards the end of the paper we review two of these important models that can benefit from the proposed analysis.

Keywords: Multi-agent systems; Autonomous agents; Equilibrium analysis; Matching

1. Introduction

In this paper we consider the problem of agents engaged in a distributed costly two-sided search for partners [8] in Multi-Agent Systems (MAS). The problem is often classified as a matching problem, since the agents' goal is to form pairwise partnerships. In this problem each agent is satisfied with only one partner and gains no utility from extending (upon finding a partner) its partnership further or from operating on its own. The matching problem is a unique variant of the general coalition formation model and its main incentive is similar to the one which drives coalitions of agents: throughout partnering, the agents can operate more effectively and coordinate their activities [39], thus increase the participants' benefits [7].

Various centralized matching mechanisms can be found in literature [3,10,14]. However, in many MAS environments, in the absence of any reliable central matching mechanism, the matching process is completely distributed. In a distributed matching model the agents need to search for partnering opportunities. The agents learn about new

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partnering opportunities (and the benefits encapsulated in them) through bilateral interactions. The search process is considered two-sided when all agents in the environment engage in search. Thus a partnership eventually formed is the result of the combined search activities of both sides of the interaction (i.e., the agents forming it). Similarly, the two-sided nature of the search suggests that a partnership between a pair of agents is formed only if it is mutually accepted by them.

This concept of two-sided search for forming partnerships can be found in many traditional economical applications such as the marriage market [40] and the job market [27]. It can also be found in many MAS applications [22], e.g., buyer and seller agents operating in electronic marketplaces and peer-to-peer distributed applications.[2] An important class of such applications includes secondary markets for exchanging unexploited resources. An exchange mechanism is used in those cases where selling the resources is not the core business of the organization or when the overhead for selling them makes it non-beneficial. For example, through a two-sided search, agents representing different service providers can exchange unused bandwidth [37] and communication satellites can transfer communication with a greater geographical coverage. In all these applications an agent can gain a utility only if it eventually partners with another agent. However, once a partnership is formed, adding more agents as partners does not produce any additional benefit.

The main idea of this paper is that a distributed two-sided search in MAS environments should take into consideration agents' capability to use parallel (simultaneous) interactions with other agents. This is in comparison to the traditional models found in the two-sided search literature [8,40] where the agents' search is conducted in a purely sequential manner: each agent locates and interacts with one agent in its environment at a time.[3] Autonomous computer agents have unique inherent filtering and information processing capabilities and, most important, the ability to efficiently (in comparison to people) maintain concurrent interactions with several other agents at each given time [2,15,21]. This way an agent can make a decision at each stage of its search based on interactions with several other agents (instead of one). Such use of parallel interactions in search is favorable especially when the search is costly, as explained in the following paragraphs. The transition into using this new search technique results in new dynamics in MAS environments and consequently new equilibrium structures. Specifically, we consider environments where the agents are associated with two possible types (i.e., a buyer and a seller) and only agents of one of the types use the parallel interaction search method. While this model is self contained and associated with specific applications (as illustrated in the following paragraphs) it can also be used for understanding the dynamics formed in models where agents of all types use parallel search. The various aspects concerning the transition to the latter model are discussed towards the end of the paper.

The motivation for using the parallel search technique is mainly the existence of search costs. These costs are a common inherent part of MAS environments where there is no central source that can supply full immediate reliable information on the environment and the different opportunities that can be found in it. The costs reflect the resources (not necessarily monetary) that need to be invested/consumed by an agent to perform its search activities (e.g., the cost associated with the interaction and negotiation between agents, locating other agents, analyzing and comparing offers, decision making, self-advertisement and the cost of maintaining the agent in an idle state until finding a partnership). The introduction of search costs leads to a more realistic description of MAS environments. Many authors have argued that recent advances in communication technologies reduce search costs and other environmental inefficiencies in MAS environments [6]. However the general agreement is that these cannot be ignored completely [2] and should be integrated into the agents' expected utility computation process, given their specific search strategy. Others have argued that the search cost for locating an opportunity is insignificant compared to the utility encapsulated in most opportunities. Nevertheless the growing interoperability between different systems and environments in the internet age, followed by a phenomenal increase in the number and complexity of opportunities available, makes the overall cost of acquiring such information an important parameter that needs to be considered when forming the agents' strategies [9,21,36].

Given the search cost, the key issue for each agent engaged in a distributed two-sided search is to determine the set of agents with whom it is willing to form a partnership. By forming a partnership the agent gains an immediate

[2] The use of the term "partnership" in this context refers to the agreement between two individual agents to cooperate in a pre-defined manner. For example, in the buyer-seller application a partnership is defined as an agreed transaction between the two parties [16].

[3] As we report in the related work section, the use of parallel search was suggested for problems of a single searcher [29]. However, these were merely optimization problems that did not concern equilibrium dynamics.