Environments for Multiagent Systems
State-of-the-Art and Research Challenges

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Abstract. It is generally accepted that the environment is an essential compound of multiagent systems (MASs). Yet the environment is typically assigned limited responsibilities, or even neglected entirely, overlooking a rich potential for the paradigm of MASs.

Opportunities that environments offer, have mostly been researched in the domain of situated MASs. However, the complex principles behind the concepts and responsibilities of the environment and the interplay between agents and environment are not yet fully clarified.

In this paper, we first give an overview of the state-of-the-art on environments in MASs. The survey discusses relevant research tracks on environments that have been explored so far. Each track is illustrated with a number of representative contributions by the research community. Based on this study and the results of our own research, we identify a set of core concerns for environments that can be divided in two classes: concerns related to the structure of the environment, and concerns related to the activity in the environment. To conclude, we list a number of research challenges that, in our opinion, are important for further research on environments for MAS.

1 Introduction

There is a general agreement in the multiagent research community that environments are essential for multiagent systems (MASs). Yet most researchers neglect to integrate the environment as a primary abstraction in models and tools for MASs, or minimize its responsibilities. As a consequence, a rich potential of applications and techniques that can be developed using MASs is overlooked.

Popular frameworks such as Jade [9], Jack [44], Retsina [79] or Zeus [58] reduce the environment to a message transport system or broker infrastructure. Well-known methodologies such as Message [25], Prometheus [66] or Tropos [12] offer support for some basic elements of the environment, however they fail to consider the environment as a first-class entity. Standard literature on MASs
used for education, including [73, 93, 45], only deals very briefly with the topic of environments. Even in the FIPA [34] specifications it is hard to find any functionality for the environment beyond message transport or broker systems. Restricting interaction to inter-agent communication neglects a rich potential of possibilities for the paradigm of MASs.

Researchers working in the domain of situated MASs traditionally integrate the environment as a first-class entity in a MAS. In situated MASs, the environment is an active entity with its own processes that can change its own state, independent of the activity of the embedded agents. Inspired by biological systems, several researchers have shown that the environment can serve as a robust, self-revising, shared memory for agents. This can unburden the individual agents from continuously keeping track of their knowledge about the system. Moreover, it enables the agents to use their environment as an excellent medium for indirect coordination. Gradient fields and evaporating marks in the environment can guide agents in their local context and as such facilitate the coordination in a community of agents in a decentralized fashion. Several practical applications have shown how the environment can contribute to manage complex problems. There are examples in domains such as supply chain systems, network support, peer-to-peer systems, manufacturing control, multiagent simulation etc. Since the exploitation of the environment in MASs results in better manageable solutions, it is a promising paradigm to deal with the increasing complexity and dynamism of future system infrastructure and more advanced problem domains, e.g. ad hoc networks or ubiquitous computing.

Despite the large amount of work in the domain of situated MASs, we are just at the very beginning of understanding the complex principles behind the concepts related to the environment and the interplay between agents and the environment. This paper aims to contribute in three ways. First we give an overview of the state-of-the-art on environments for MASs. Based on this study as well as the results of our own research, we identify a set of core concerns for environments, as a second contribution. Third, we outline a number of research challenges that, in our opinion, are important for the future development of environments for MASs.

2 Organization of the Paper

In Sect. 3 we start with an overview of the state-of-the-art on environments for MASs. Studying MAS literature with a focus on environments is a tough job. During our study, we encountered two types of difficulties: (1) the term environment has several different meanings, causing a lot of confusion, (2) the functionalities associated with the environment are often treated implicitly, or integrated in the MAS in an ad-hoc manner.

The confusion on what the environment comprises is mainly caused by mixing up concepts and infrastructure. Sometimes, researchers refer to the environment as the logical entity of a MAS in which the agents and other objects/resources are embedded. Sometimes, the notion of environment is used to refer to the