Chapter 1
Web Services Integration in Multi-Agent Systems

Davide Guidi
Imperial College London, UK

Mauro Gaspari
University of Bologna, Italy

Giuseppe Profiti
University of Bologna, Italy

ABSTRACT
The development of distributed systems is influenced by several paradigms. For example, in the last few years, great emphasis has been placed on Service Orientation. In addition, technologies such as Web services are now considered standard, deployed in common development tools and widely used. However, despite this recent trend, the constantly growing number of powerful personal devices will inevitably revitalize the interest in another paradigm known as Autonomous Agents. Agents are in fact considered one of the main building blocks of the emerging next generation Web infrastructure. Web services are very important resources for agents. Agents should be able to retrieve, execute and compose Web services, providing an intelligent and personalized support to users. On the other hand, agents should also be able to export their functionalities as Web services in order to be fully integrated in the Service Oriented paradigm. In this chapter we present a survey of the current state of the art about Web services integration in open Multi-Agent Systems (MAS). Considering these approaches, we identify a set of requirements needed to achieve full integration and we present a communication infrastructure, which satisfies these requirements.

INTRODUCTION
A Multi-Agent System (MAS) is a system composed of several agents, collectively capable of reaching goals that are difficult to achieve by an individual agent or monolithic system. Agents in MAS may range from hardware robots to software agents realized as processes/threads (softbots) or interacting in distributed systems. This chapter is only focused on software agents, although some of the results and considerations that we present could also apply to a hybrid MAS including both robots.
and softbots. Agents may cooperate or they may compete, or some combination of these, but there is some common infrastructure that results in the collection being a system, as opposed to simply being a set of autonomous disconnected agents.

Multi-Agent System is a widely used paradigm. It can be considered the standard solution for addressing problems that require collective intelligence, negotiation and cooperation. It is also used as a software development paradigm in opposition to big monolithic applications, which can be too much complex and hard to maintain and extend. A MAS is also useful in systems with scarce resources, such as embedded systems. In a MAS, agents are autonomous, they have knowledge of local information and usually there is no central management (Nilsson, 1998). In other words, a MAS intrinsically shares many aspects of peer-to-peer systems despite the fact that it can be realized using centralized components. Some of these systems are composed of a fixed set of interacting agents that are created at the beginning of the application. More interesting systems are open: they are composed by agents that can be dynamically added and removed from a running MAS.

The Internet is one of the major fields of application for an open MAS, where user-agents can automate tasks for users (such as searching for information and buying products), avoiding long Web surfing sessions. Such user-agents can be tailored to specific Web pages following ad hoc approaches, or they can be realized by accessing other agents or available Web services in a more general perspective. For these agents, Web services represent the standard Web API to provide remote services to applications over the Internet.

In this chapter we investigate the principal aspects concerning the integration of an open MAS with Web services, presenting a survey of the current state of the art, as well as a generic approach to seamlessly integrating agents and Web services in a bidirectional way. The rest of the chapter is structured as follows. In the first section we provide some background information about the terminology and some basic concepts. In the section entitled “Integrating agents and Web services”, we introduce the technical issues and the open problems related to the integration of Web services in Multi-Agent Systems. In the section entitled “Approaches to Web service Integration” we present the current state of the art, discussing a number of integration techniques. Considering those different solutions, the section “Achieving Full Integration” identifies a set of 4 requirements needed for full integration. These requirements are fully satisfied by NOWHERE, the solution proposed by the authors, which is presented and compared with the other platforms in the section “The NOWHERE Agent Communication Infrastructure”. In the section entitled “Future Research Directions” we present an interesting open issue, the Semantic Matching of Web services with respect to agents’ request, identifying some promising solutions. Finally, in the last section we present the conclusions of our survey.

BACKGROUND: TERMINOLOGY AND BASIC CONCEPTS

This section defines the key terms and concepts used in the rest of the chapter. An open Multi-Agent System is a MAS where new agents can be added dynamically to cooperate with the existing ones. Agents can also dynamically leave the MAS when their tasks terminate. An open Agent Platform is a runtime infrastructure that supports a minimal set of basic mechanisms: creating and terminating agents, naming agents (providing a notion of agent identity: a property that distinguishes each agent from all others) and connecting agents (supporting their communication).

Web services are procedure calls done over the Hypertext Transfer Protocol (HTTP), usually on the well-known port 80. Web services are usually implemented using standard libraries and applications such as Axis and Tomcat, which are
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