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An agent-based service-oriented integration architecture for collaborative intelligent manufacturing

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Abstract

The rapidly changing needs and opportunities of today's global market require unprecedented levels of interoperability to integrate diverse information systems to share knowledge and collaborate among organizations. The combination of Web services and software agents provides a promising computing paradigm for efficient service selection and integration of inter-organizational business processes. This paper proposes an agent-based service-oriented integration architecture to leverage manufacturing scheduling services on a network of virtual enterprises. A unique property of this approach is that the scheduling process of an order is orchestrated on the Internet through the negotiation among agent-based Web services. A software prototype system has been implemented for inter-enterprise manufacturing resource sharing. It demonstrates how the proposed service-oriented integration architecture can be used to establish a collaborative environment that provides dynamic resource scheduling services.

Keywords: Enterprise collaboration; Virtual enterprise; Software agents; Web services; Service-oriented architecture

1. Introduction

The manufacturing enterprises of the 21st century are facing an environment where markets are frequently shifting, new technologies are continuously emerging, and competition is globally increasing. The rapidly changing needs and opportunities of today's global market require unprecedented levels of interoperability to integrate diverse information systems to share knowledge and collaborate among organizations. Fully integrated enterprises are being replaced by business networks in which each participant provides others with specialized services. Traditional IT infrastructures in which applications were managed and owned by one enterprise are being switched to networks of applications owned and managed by many business partners. Through this revolution, the temporary alliance of enterprises (so-called Virtual Enterprise, or VE) as a whole can be more robust and agile to the transient market opportunities.

Toward this direction, enterprises all realize the cost of automating cross-organizational transactions is very high, especially for the dynamic VE processes automation. In view of the fact that distributed organizations are generally managed using heterogeneous software systems running on heterogeneous computing environments, the recently emerged Web Services technology provides a higher-level interoperability for leveraging business activities across the Web either within an enterprise or among collaborating enterprises. Manufacturing firms have been putting their efforts to provide practical access methods to their existing information systems by leveraging the Internet and Web. However, what they have done today always assumes a collaboration network under a pre-assumed agreement. On the other hand, pure Web-based technologies, including Web services, cannot fulfill the needs of VE applications, particularly in that: (1) the Web service discovery mechanism is not enough for driving VE creation at run time; (2) the Web service description is not enough for driving VE

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services description that is semantically intensive; and (3) the Web services business processes description, orchestration, and security have hardly reached a maturity for process automation [1,2].

Intelligent software agents, which have been applied to enterprise integration for wrapping legacy systems, not only provide an approach for functional integration, but also promote business intelligence and collaboration among enterprises for their inherited characteristics of communication, interaction, cooperation, pro-activeness, and autonomous intelligent decision making. We believe that the combination of Web services and software agents provides a promising computing paradigm for efficient service selection and integration of inter-organizational business processes. This paper proposes an agent-based service-oriented integration architecture, wherein enterprise Web services are dynamically orchestrated on the Internet using agent behaviors built in them. A prototype system is designed to demonstrate the VE creation process in response to a resource requirement order.

The rest of this paper is organized as follows: Section 2 provides an introduction and analysis of Web services, software agents, and their applications to enterprise integration; Section 3 discusses the requirements of VE collaboration faced by manufacturing enterprises and addresses the integration of software agents and Web services technologies; Section 4 presents an agent-based service-oriented system architecture for manufacturing enterprises collaboration; Section 5 describes a case study on virtual enterprise creation in response to a customer's order; Section 6 depicts an implemented software prototype for inter-enterprise manufacturing resource sharing; Section 7 concludes the paper with some perspectives.

2. Service-oriented computing and software agents

Service-oriented computing (SOC) is considered as a new computing paradigm after the object-oriented paradigm. It utilizes services as fundamental elements for developing applications/solutions. Services are autonomous platform-independent computational elements that can be described, published, discovered, orchestrated and programmed using XML for the purpose of developing massively distributed interoperable applications.

2.1. Service-oriented computing and Web services

Web services technology is part of the SOC paradigm and can be considered as an implementation of the SOC model. Web services are featured with application, platform and provider independence. They provide an appropriate paradigm for building open large-scale application environments, such as supply chains. In such environments, services are not treated as isolated and one-time affairs but rather as elements of an interactive, dynamic and collaborative architecture. Service collaboration within or across environments is modeled in terms of supported transactions or processes that are subject to norms or protocols specified for certain business domains. Services are thereby orchestrated vertically within one environment, or horizontally across multiple environments. As a result, an individual environment streamlines services in terms of internal transactions while restrains its function scope to be highly specific to the targeted user group. Multiple environments collaborate in order to extend their business chains. Web services have been supported by major IT vendors through their commercial platforms such as Microsoft's .NET [3] and SUN's J2EE [4]. There are also underlying technologies behind the promoted business initiatives such as HP's Adaptive Enterprise [5] and IBM's On-Demand e-Business [6].

To support the SOC concepts, Web services must provide standards-based definitions of an interoperability communication protocol, mechanisms for service description and discovery, approaches for service composition and orchestration, as well as a basic set of mechanisms for quality of service. The first initiatives of Web services and today's de-fasco standards include SOAP [7], WSDL [8] and UDDI [9]. These standards together provide an open XML-based mechanism for application interoperability, service description and service discovery. In recent years, the standardization initiatives have been very active in the Web services community to push basic Web services mechanisms to business applications. Among them, most notably are the Business Process Execution Language for Web Services (BPEL4WS) [10] and ebXML (Electronic Business XML) [11] for service composition and orchestration; WS-Transaction [12] and WS-Coordination [13] for service processes interaction; and other special protocols related to security, service quality and business policies, e.g., WS-Trust [14], WS-SecureConversation [15], WS-Security [16], WS-SecurityPolicy [17], WS-Policy [18], and WS-ReliableMessage [19]. Fig. 1 shows a classification of the Web services standards mentioned above. Note that this figure does not intend to show all available Web services standards. In fact, more standards are still being proposed and developed.

J2EE and .NET are two widely accepted industrial application development frameworks for Web services.

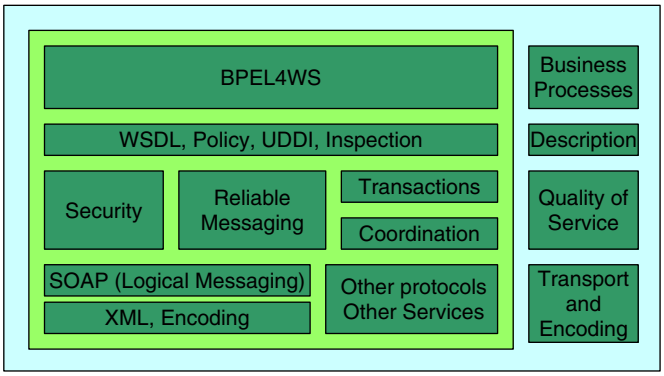

Fig. 1. Classification of Web services standards.