BROSEMWEB: A brokerage service for e-Procurement using Semantic Web Technologies

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A B S T R A C T
The Service-Oriented-Architecture (SOA) development paradigm has emerged to make an improvement in critical situations such as creating, modifying and extending solutions in the domain of business processes integration. Web services technologies are considered as the main units for SOA, for both intra- and inter-enterprise communication. Nevertheless, SOA does not have information about the events that occur in business processes, which represents the main characteristics of supply chain management. Taking this into account, this paper proposes a middleware-oriented integrated architecture with the use of semantic features (concretely with the use of Linked Data) as data provider to offer a brokerage service for the procurement of products in a Supply Chain Management (SCM). As main contributions, our system provides a hybrid architecture that combines features of both SOA and EDA between several others.

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1. Introduction

E-business has been an important issue in development of business models in recent years. For example, the e-Procurement system, that is an electronic purchasing channel where users can find, select, buy and return goods via the Internet [1]. However, e-Procurement is more than just a system for making purchases online. It provides an organized way to keep an open line of communication with potential suppliers during a business process. E-Procurement (electronic procurement, sometimes also known as supplier exchange) is the Business-to-Business (B2B), Business-to-Consumer (B2C) or Business-to-Government (e-Government) purchase and sale of supplies, work and services through the Internet as well as other information and networking systems, such as Electronic Data Interchange (EDI) and Enterprise Resource Planning (ERP) [2]. E-Procurement helps with the decision-making process by keeping relevant information neatly organized and time-stamped. The new generation of e-Procurement is now on-demand or a software-as-a-service. Under this context, Semantic Web Technologies play an important role. The notorious successes that the application of Semantic Web Technologies has achieved in B2B and e-Commerce has also lead it to be viewed as a promising technology for designing and building effective business collaboration in the enterprise. Deploying Semantic Web Services reduces the integration costs and brings in the required infrastructure for business automation, obtaining a quality of service that could not be achieved otherwise [3,4]. Furthermore, Semantic Web Technologies allow combine architectural styles for software development such as Service-Oriented Architecture (SOA) and Event-Driven Architecture (EDA) in order to develop effective e-Procurement systems. SOA as an architectural paradigm for creating and managing “business services” that can access these functions, assets, and pieces of information with a common interface.

regardless of the location or technical makeup of the function or piece of data [5]. Furthermore, the appearance of the new concept of Linked Data [6] allows an improvement in the discovery of new information in the Internet, including consumption from existing Web Services [7]. EDA is an architectural paradigm based on using events that initiate the immediate delivery of a message that informs to numerous recipients about the event so they can take appropriate action [8]. An EDA combined with SOA, provides that ability to create an architecture that enables business collaborations in such a way that companies can proactively address and respond to real-world scenarios in real time. Based on this understanding, in this paper we propose an e-Procurement system based on Semantic web technology called BROSEMWEB. BROSEMWEB offers a brokerage service to facilitate the business processes integration in procurement. Our brokerage service for e-Procurement presented here is an extension of a previously work [9] where BROSEMWEB provides a virtual marketplace where people, agents and trading partners can collaborate by using current semantic Web in a flexible and automated manner. BROSEMWEB provides the following contributions: (a) A hybrid architecture that borrows features from service-oriented and event-driven architectures to provide support for B2B collaborations; (b) A business processes pattern management component for the orchestrations of business processes; (c) A mechanism based on UML sequence diagrams to monitor the interactions involved in business collaborations; (d) A Semantic Web Services-based management component with capabilities for discovering the availability, performance, and usage, as well as the control and configuration of Semantic Web Services; (e) An execution event publish/subscription mechanism to incorporate information into business processes and decisions through event publication; (f) A messaging service that provides a guaranteed delivery and processing in a reliable way.

This paper is organized as follows: Section 2 presents recent advances in the state of the art of e-Procurement systems. Section 3 describes BROSEMWEB's internals and functionality. Section 4 presents a case study for a multi-level e-Procurement scenario. Section 5 presents the evaluation of results and performance of BROSEMWEB. Section 6 describes the future directions. Finally, the concluding remarks are presented in Section 7.

2. State of the art

In recent years, several works have been proposed with the aim of developing e-Procurement systems. Koumoutsos and Thramboulidis [10] proposed an approach that focuses on knowledge modeling, formalization, representation and management in the domain of e-Negotiation. The proposed approach exploits ontologies, Service Oriented Architectures, Semantic Web Services, software agent platforms and knowledge-bases to construct a framework that favors dynamically adapted negotiation protocols, negotiation process visualization and management, modeling and preference elicitation of the negotiated object and automatic deployment of negotiation interfaces. A knowledge-based intelligent e-Commerce system for selling agricultural products was presented by Wen [11]. The KIES system provides feasible solutions or actions based on the results of rule-based reasoning. KIES integrates a database, a rule base and a model base to create a tool of which managers can use to deal with decision-making problems via the Internet. Monitoring process was not covered in both works, also a messaging service was not considered.

Sun et al. [12] presented an agent and a Web service based architecture for exception handling in e-Procurement. Agent technology is applied to deal with the complex, dynamic, and distributed e-Procurement process, while Web service technology is applied to provide scalability and interoperability. In this architecture, different tasks in the e-Procurement process, such as searching, negotiating, supplier selection, contracting, monitoring, and exception handling, are assigned to different agents, which are wrapped as Web services. Liu et al. [13] reviewed the practicality and suitability under a Cased-Based Reasoning approach for procurement selection through the development of a prototype case-based procurement advisory system. In this prototype system, procurement selection cases are represented by a set of attributes elicited from experienced procurement experts. The system is powered by a fuzzy similarity retrieval mechanism, which gives a greater accuracy than the normal similarity retrieval process. Web services Management and Web services orchestration are not considered in these works, but monitoring process was covered.

Liu et al. [14] proposed an agent-based architecture for an e-Procurement system in which agent technology is applied to deal with the internal and external uncertainties. Through the collaboration and interaction between different agents, the architecture proposed can enhance the flexibility to handle unexpected exceptions, thus leading to agile procurement management. To validate the feasibility of this approach, a case study has been conducted to investigate how the agents collaborate to manage the inventory disruption that may occur in a restaurant e-Procurement. Panayiotou et al. [15] presented a case study concerning the analysis of the Greek governmental purchasing process. The objective of the analysis is the identification of potential problematic areas and the design of new processes in order to maximize the possibilities of a successful implementation of a new e-Procurement system. Control and configuration of Semantic Web Services are not considered.

Hadikusumo et al. [16] proposed a decentralized database system equipped with electronic agents for material procurement. Results revealed that this system can be used to assist human purchasers to carry out solicitation in identifying suppliers, searching materials, and preparing purchase orders. Lee et al. [17] presented a procurement system with relevant parties so as to have a better coordination between supply and demand sides. This work demonstrates how to analyze the data with an Agent-based Procurement System (APS) to re-engineer and improve the existing procurement process. APS supports the data and information analyzing technique to facilitate the decision making such that the agent can enhance the negotiation and supplier evaluation efficiency by saving time and cost. Business process orchestration is considered and an e-Procurement system was developed in each work.

Albrecht et al. [18] proposed an exploration of standards required for successful e-Commerce architectures and an evaluation of the strengths and limitations of current systems that have been developed to support e-Commerce. The notion of a ubiquitous network where loosely coupled buyers and sellers can reliably find each other in real time, evaluate products, negotiate prices, and conduct transactions is not adequately supported by current systems. These findings were based on an analysis of mainline e-Commerce architectures: EDI, company Websites, B2B hubs, e-Procurement systems, and Web Services. Kima et al. [19] presented the matching between indirect procurement process and different e-Procurement systems, at both the high-level and low-level activities, for identifying and articulating the areas where various e-Procurement systems can be utilized in a hybrid and seamless manner.

Some methods were presented by Álvarez et al. [20] in order to expand user queries and a performance evaluation to retrieve public procurement notices in the e-Procurement sector using semantics and linking open data. In this work, the system developed is based on the use of Semantic Web Technologies so it is necessary to model the unstructured information included in...
public procurement notices, enrich that information with existing product classification systems and linked data vocabularies and publish the relevant data extracted out of the notices following the linking open data approach.

Jagdev et al. [21] presented the design and implementation of a unique bid auction application for procurement automation within supply chains embedded in extended and virtual enterprises. An integration and automation auction example is provided in order to illustrate semantic web applications over extended enterprises or virtual enterprises. Blau et al. [22] proposed the design of a multidimensional procurement auction for trading service compositions and the analysis of strategies for service providers that participate in the procurement process. Also, a simulation-based analysis based on a reinforcement learning model of bundling and unbundling strategies of service providers that participate in the auction is provided. García-Sánchez et al. [23] presented SEMMAS, an ontology-based framework for seamlessly integrating Intelligent Agents and Semantic Web Services by making use of ontologies to facilitate their interoperation. A solution based on a fully fledged architecture and proof-of-concept implementation is presented as a serves a meeting point for both service consumers and service providers through a simple web-based graphical interface.

Du [24] proposed an automatic e-tendering system that implements an automatic negotiation process over the Semantic Web in which Web pages provide information not only through their content, but also through the properties of that content. The e-tendering system integrates a negotiation process that considers bargaining power and risk preference of negotiating parties. The semantic data then are used to select tenders or to determine negotiation strategies. Lee and Kwon [25] proposed a new negotiation support system to incorporate causal relationships of negotiation terms in the process of B2B negotiation, on the basis of a cognitive map. The system called CAKES-NEGO (Causal Knowledge-driven Expert System) suggests that causal relationships of negotiation terms could be explicitly represented by using the cognitive map as knowledge representation vehicle as well as inference engine. Cognitive maps can illustrate causal relationships among the factors describing a given object and/or problem, and it can also describe experts’ tacit knowledge about a certain object. A fuzzy cognitive map (FCM) is an extension of a cognitive map with the additional capability of representing feedback through weighted causal links. Jimenez-Domingo et al. [26] presented CARL, a novel, cutting-edge, interoperative and integration-oriented language based on Semantic Technologies that provides a formal model and semantics to enable Complex Application management and integration in PaaS environments in order to benefit from a very specific set of rules to enact cross-domain integration and tackling several challenges that could not occur in open spaces like the World Wide Web. Lopez-Cuadrado et al. [27] presented SABUMO, a

<table>
<thead>
<tr>
<th>Proposal</th>
<th>Approach</th>
<th>Motivation</th>
<th>Underlying Technology</th>
<th>Tool support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun et al. [12]</td>
<td>Agent-based architecture for searching, negotiating, supplier selection, contracting, monitoring, and exception handling in e-Procurement</td>
<td>e-Procurement</td>
<td>Intelligent agents wrapped as Web services and Rule-based system</td>
<td>An Java-based e-Procurement prototype system</td>
</tr>
<tr>
<td>Liu et al. [14]</td>
<td>Agent-based architecture to manage exception during the procurement process</td>
<td>e-Procurement</td>
<td>Intelligent agents</td>
<td>Not provided</td>
</tr>
<tr>
<td>Hadikusumo et al. [16]</td>
<td>A decentralized database system equipped with electronic agents for material procurement</td>
<td>e-Procurement</td>
<td>Intelligent agents</td>
<td>Electronic purchasing agent (EPA)</td>
</tr>
<tr>
<td>Lee et al. [17]</td>
<td>Agent-based architecture to achieve responsiveness of the dynamic market enabling market data analysis and effective order processing</td>
<td>e-Procurement</td>
<td>Intelligent agents and Data Mining</td>
<td>Agent-based procurement system (APS)</td>
</tr>
<tr>
<td>Jagdev et al. [21]</td>
<td>How web services execution environment could be used to implement an auction process</td>
<td>B2B and B2C auction</td>
<td>Semantic Web</td>
<td>WSML ontologies within the WSMX environment are presented to develop auction processes</td>
</tr>
<tr>
<td>García-Sánchez et al. [23]</td>
<td>Solution based on a fully fledged architecture that serves as a meeting point for both service consumers and service providers through a simple web-based graphical interface by making use of ontologies</td>
<td>B2B and B2C transactions</td>
<td>Intelligent agents and Semantic Web</td>
<td>Semantic web services and Multi-Agent System framework (SEMMAS)</td>
</tr>
<tr>
<td>Lee and Kwon [25]</td>
<td>Intelligent negotiation using causal knowledge as well as inference mechanism supported by fuzzy cognitive map</td>
<td>B2B negotiation</td>
<td>AI techniques</td>
<td>CAKES-NEGO</td>
</tr>
<tr>
<td>Lopez-Cuadrado et al. [27]</td>
<td>Designing and annotating business processes, executing the business processes and the rating of these business processes by other users</td>
<td>Knowledge sharing</td>
<td>Semantic Web Technologies</td>
<td>SABUMO</td>
</tr>
</tbody>
</table>
framework based on ontologies that allows experts to represent and share their knowledge with other experts by means of shared and controlled vocabularies. The framework also allows the execution of business processes represented by experts. The execution of this knowledge does not require the installation of complex AI programs. Martin-Vicente et al. [28] presented a semantic approach to improve recommendation results transparently to the users. On the one hand, implicit trust networks are automatically build in order to incorporate trust and reputation in the selection of the set of like-minded users that will drive the recommendation. A measure of practical expertise is also proposed by exploiting the data available in any e-commerce recommender system – the consumption histories of the users.

Breslin et al. [29] presented a short review of Semantic Web standards, languages and technologies followed by a more detailed review of applications of Semantic Web computing in industry. Theoretical considerations as well as use cases and experience reports on the topic are covered, and some current challenges and opportunities in the domain are also presented. Liang et al. [30] proposed a methodology to appraise performance of the IA and demonstrate the use in the B2C e-commerce negotiation process. An experiment was conducted to acquire empirical data and a survey was implemented to confirm advantage of the use of the IA. The computational results indicate that the proposed approach successfully evaluates IA performance and significantly distinguishes groups of using (vs. not using) the negotiation mechanism in B2C e-commerce.

In order to analyze more precisely some of the works described above and compare them with our proposal, we have defined a
comparative table (see Table 1) which summarizes relevant issues of these researches taking into account the following criteria: (1) Underlying technology used/implemented, (2) Approach proposed, (3) Motivation and (4) Tool support if is provided.

Based on results obtained from the comparative analysis summarized in Table 1 we can conclude that current initiatives for developing e-Procurement systems suffer from several drawbacks such as: (a) they do not consider the use of semantic technologies in e-Procurement process; i.e., they only consider Semantic Web Technologies for knowledge sharing, (b) Unlike our proposal, some e-Procurement system are based on an agent-based approach; therefore, they are focused on rule-based systems and old-fashioned technologies were implemented and (c) many do not have tool support or some works are in preliminary design (prototype) phase without any implementation, which implies more development time and effort in e-Procurement scenarios. BROSEMWEB tries improving these deficiencies.

3. BROSEMWEB: architecture and functionality

BROSEMWEB has a layered design (see Fig. 1) that allows for scalability and easy maintenance due to allocation of tasks and responsibilities. BROSEMWEB presents a component–based and hybrid architecture, borrowing features from SOA and EDA. In an SOA context, BROSEMWEB acts as a Business Process Management (BPM), facilitating the creation and execution of highly transparent and modular process-oriented applications and enterprise workflows. On the other hand, EDA provides a software infrastructure designed to support a more real-time method of integrating event-driven application processes that occur and are largely defined by their meaning to the business and their granularity.

The proposal focuses on ensuring that interested parties, usually other applications, are notified immediately when an event happens, regardless of the event’s granularity. These features are performed by the brokerage service.

3.1. Architecture description and its components

The BROSEMWEB’s architecture is shown in Fig. 2. Each component has a function explained as follows:

**SOAP message analyzer** determines the structure and content of the documents exchanged in business processes involved in e-Procurement scenarios. In BROSEMWEB, this component determines the information involved in the incoming SOAP messages by means of XML parsers and tools. A DOM API is used to generate the tree structure of the SOAP messages, while the Simple API for XML (SAX) is used to determine the application logic for every node in the SOAP messages. A set of JAXP-based Java classes was developed to build the XML parser.

**Service registry** is the mechanism for registering, publishing and update information about business processes, products and services among e-Procurement partners. We used a UDDI node, which is an industry initiative to create a platform-independent, open framework for describing services, discovering businesses, and integrating business services. In BROSEMWEB, our UDDI node is used to commercial enterprises, services and products both are classified and registered. For the classification of business processes, products and services in the registry, we used broadly accepted ontologies/taxonomies like NAICS, UNSPSC and RosettaNet. NAICS is a standard classification system for North American Industry; UNSPSC provides an open, global multi-sector standard for efficient, accurate classification of products and services and RosettaNet defines the technical and business dictionaries.

**Subscription registry** is used to registering interactions in which systems publish information about an event to the network so that other systems, which have subscribed and authorized to receive such messages, can receive that information and act on it appropriately. According to the cause of an event, knowledge often referred to as event causality. In this work, we have considered both vertical and horizontal causality meaning that the event’s source and cause reside both on different and on the same conceptual layers in an architectural stack, respectively. In vertical causality, this registry has a support for storing execution events that represent runtime occurrences such as service or component invocations. Lifecycle management event (stopping or starting business process without exceed defined limits or ranges) are also part of a vertical causality and are considered as future work. In horizontal causality, this registry has support for the events in the layers of Platform, Component and Business. Platform-layer events are activities, such as the modification of a data source or the addition of a new service. Component-layer events are component-level activities, for example the transformation of a view or a state-machine transition. Finally, Business-layer events signify business-level activities, such as the creation of a new user or the removal of an account.

**Discovery service** is a component used to discover business processes implementations and being able to find business processes at runtime to create new business processes that is highly desirable. A key step in achieving this capability is the automated discovery of business processes described as Web services. In this sense, this component discovers Semantic Web Services like authentication, payments to mention but a few. These Web services can be obtained from suitable service providers and can be combined into innovative and attractive product offerings to customers. When there is more than one service provider of the same function, it can be used to choose one service based on the customer requirements. Inside the discovery service, there is a query formulator, which builds queries based on the domain ontology that will be sent to the registry service. This module retrieves a set of suitable services selected from the previous step and creates feasible/compatible sets of services ready for binding. The discovery service uses sophisticated techniques to dynamically discover web services and to formulate queries to UDDI nodes.

**Dynamic binding service** is used to binds compatible business processes described as Semantic Web Services. The binding of a semantic web service refers to how strong the degree of coupling with other Web Services is. For instance, the technology of one semantic web service supplier might be incompatible with that of another, even though the capabilities of both of them match with some requirements. In this sense, the module acts as an API wrapper that maps the interface source or target business process to a common interface supported by our proposal.

**Dynamic invoker** transforms data from one format to another. This component can be seen as a data transfer object (i.e., request or response) flowing between the requestor to the supplier applications of Web services. We used Web Services Invocation Framework (WSIF) that is a simple Java API for invoking web services, no matter how or where the services are provided.

**OWL-S document analyzer** validates OWL-S documents that describe business processes by their interfaces that are provided and used by users, using XML Schema for the specification of information items either product technical information or business processes operations. In this context, this component reports the business processes operations, input and output parameters and their data types in a XML DOM tree.

**WS-RM-based messaging service** is the communication mechanism for the collaboration among the actors. In order to bring effective communication, information technologies are considered to be the ideal solution for solving the problems related to reliability. Reliability of Web services is impacted by several factors including but not limited to the performance and fault-tolerance.
characteristics and the extent to which Web services can handle concurrent customers access, among others. Our architecture uses the Web Services Reliable Messaging (WS-RM), which is a protocol that provides a standard, interoperable way to guarantee message delivery to applications. In this sense, our proposal provides a guaranteed delivery and processing that allows in a reliable way, delivery of messages between distributed applications in the presence of software components, systems, or network failures through WS-RM.

Response formatter is used to receive the responses from the suppliers about a requested product. This module retrieves useful information from the responses and builds a XML document with information coming from the service registry and the invocations’ responses and is presented in HTML format using the Extensible Stylesheet Language (XSL). The answer contains information pertaining to the requested product and the electronic address of the enterprise that offers that product.

Workflow engine coordinates Web services by using a BPEL-based business process language and consists of building a fully instantiated workflow description at design time, where business partners are dynamically defined at execution time. For this reason, we have designed and implemented a repository of generic BPEL workflow definitions that describe increasingly complex forms of recurring situations. This repository contains workflow patterns of interactions involved in an e-Procurement scenario. These workflows patterns describe the types of interactions behind each business process, and the types of messages that are exchanged in each interaction.

Semantic layer bridge (SLB) interprets all the queries which comes from Service Layer (from SOAP Messages Analyzer or Discovery Service components) in order to infer if the knowledge which will be provided to these modules could come from the ancient directory layer or some extra information could be provided by some of the components which have been added to this directory layer. This component has two main modules:

1) **Data source selector:** It analyzes the information and selects the appropriate data source (legacy databases or information from linked data datasets).

2) **Data query manager:** Depending on the source selected in “Data Source Selector” module, this module will be throwing a process to retrieve the information. If the Data Source Selector returns that the information should be obtained from legacy databases, the process which will be thrown, it is called “Relational DB Querier”. However, if the information requested is more feasible to be stored in the datasets of Linked Data, the “Semantic (LD) Querier” process will be thrown.

Linked Open Data Extractor (LODE) analyzes the information stored in the Linked Open Data Cloud (new component represented in the redefined directory layer) and if this information is necessary in some moment, to extract it. It has two main modules:

1) **Data finder/analyser:** This module is called when the Data Source Selector module of SLB component tries to know if the information requested could be found it in the legacy databases or in the new Linked Data datasets. The aim of this module for hence is to try to navigate in the Linked Data cloud to search concrete information.

2) **Data extractor:** Once the “Data Source Selector” has determined that the information should come from Linked Data information source and the Semantic (LD) Querier has been thrown, this module will extract the appropriate information.

According to the emphasis on automation, BROSEMWEB can be accessed in two modes of interaction, either as a proxy server or as an Internet portal. In the first mode, the brokerage service can inter-operate with other systems or software agents. In the second mode, our architecture acts as an Internet portal that provides to the users a range of options among the Semantic Web Services available through the brokerage service.

### 3.2. Main functionalities of BROSEMWEB

BROSEMWEB provides 4 main functionalities for carrying out the e-Procurement of products and services. These functionalities are explained in a detailed way below:

1) **Semantic Web Services discovery** includes locating business processes that provide a particular service which can be used by e-Procurement process. BROSEMWEB provides basic services for publishing and querying Web services and represents the basic operations. The following example explains the structure and behavior of the Web services discovery in BROSEMWEB. It assumes that a customer has a production line which cannot be stopped. At certain moment, the customer detects his stock levels have decreased and therefore needs to find what suppliers are available. By doing this, the customer must select the type of the product that wants from a range of options offered through an Internet portal. Then, BROSEMWEB obtains the request and formulates a query to the service registry. The result to the query is a list of all the suppliers that includes the requested product in their stocks. Next BROSEMWEB extracts the required information and builds an XML document and is presented in HTML using a style sheet. The answer contains information relating to the supplier and product. An advantage of this system is that customer can know what registered enterprises can offer goods or services, through basics Web services.

2) **Semantic Web Services orchestration** allows coordinating Web services in order to define new business processes. The composition of Web services is defined as a process that enables the creation of composite services, which can be dynamically discovered, integrated and executed to meet user requirements. Composite Web services can be created in both design and execution time. In BROSEMWEB, for the execution of a composite Web service it is firstly necessary to locate a suitable template from the BPEL repository that describes the intended commercial activities. In this schema, the templates are completely determined since commercial partners are known beforehand. For instance, if a customer that might be interested in buying a several books in a store that offers either the lowest price or the minimum delivery time, BROSEMWEB will retrieve the location of the BPEL workflow template that uses the purchase-criteria selected from a database. Once the template is located, BROSEMWEB uses the OWL-S document and the related configuration files in order to instantiate them. BROSEMWEB obtains the templates that can be used to find the suppliers that offer the product required by the customer. A query to a database containing the OWL-S documents provided by BROSEMWEB can retrieve the appropriate Web services to obtain a number of pieces of commercial information like price, quantity, delivery time and purchase access point books. To complete the templates, two steps should be considered. First, is necessary to include the namespaces of the services on top of the BPEL document identifying them with a number. Second, is to complete the executable BPEL document by including or modifying some elements. Once Web services namespaces, partner-Links, input and output variables and invocations to external services have been included, a namespace and a partner-Link must be added for each Web service along with input and output variables. The instantiated templates are allocated in a BPEL engine for execution. To communicate with
the running workflow, BROSEMWEB builds SOAP messages containing the information provided by the customer. Following our example, the customer sends to the running workflow, the book code and the required quantity in a SOAP message. The workflow verifies also that the sum of all the quantities is at least the quantity requested by the customer. If it is not true, an empty list is sent back to the customer as response, which means that customer’s request could not be completely fulfilled by any of the registered stores. Whenever the workflow has been successfully terminated, it sends back to the customer the list of suppliers satisfying his requirements. Then, the workflow is de-allocated from the workflow engine. After the customer selects the suppliers, a BPEL template for placing a purchase order is now retrieved from the repository, completed and executed as described before. By enacting this workflow the purchase orders are sent to the suppliers and the corresponding answers from each supplier are eventually received. So far, we have only shown one example that illustrates the use of a composite semantic web service. However, a wide variety of other composite Web services involving some optimization criteria have also been developed and tested, like minimum delivery time and distributed purchases, to mention a few.

3) **Process Activity Monitoring** offers capabilities for business activities monitoring. For the monitoring process, it is necessary listen the request/response SOAP messaging of Web service-based business collaboration. The SOAP messaging identifies the users and their communications during the long-running interactions and their collaboration. BROSEMWEB intercepts all SOAP messages to generate a UML sequence diagram from the information about the users and the order in which the messages are exchanged. For the monitoring of activities, a set of Java classes has been developed to represent a UML diagram in a SVG (Scalable Vector Graphics) representation that can be visualized in an SVG enabled Internet browser. The exchange of SOAP messages during some kinds of business collaboration may be developed very quickly. Therefore, to avoid reducing the performance of the Web services execution, the dynamic generation of UML diagrams uses a buffered mechanism to deal with a fast pacing production of SOAP messages.

4) **Semantic Web Services Management** refers to the problem of monitoring and controlling the Web services themselves and their execution environment, to ensure they operate with the desired levels of quality [31]. In this sense, we developed a basic web services manager with capabilities for discovering the availability, performance, and usage, as well as the control and configuration of Web services provided by BROSEMWEB. The underlying technology used for the implementation is JMX (Java Management eXtension) [32], but conceptually could be extended to support other management technologies such as CIM (Common Information Model) and SNMP (Simple Network Management Protocol). The JMX architecture consists of three levels: instrumentation, agent and distributed services. JMX provides interfaces and services adequate for monitoring and managing systems requirements. This functionality involves abstracting resources by using components called MBeans (Managed Beans) and remote instrumented resources, accessible through JMX connectors. An MBean is a Java object that represents a manageable resource, such as an application, a service or a device. The architecture for Semantic Web Services management in BROSEMWEB is shown in Fig. 3.

The main component for web services management is a JMX Bridge, which acts as a bridge between the collection of resources managed by JMX and Web services. In BROSEMWEB, Web services interfaces to JMX are available. Rather than provide a JMX specific Web service interface, BROSEMWEB provides a Web service
interface to a manageable resource. Under our approach, the resources can be implemented on different technologies because it is only necessary to define a Web service interface for a resource. In order to do this, we used MBeans to represent the resource being managed. The JMX Bridge provides information that identifies or describes the MBean instance that represents a specific managed resource. The most significant aspect of our approach is a JMX-based management Web service that allows the storage of MBeans within a JMX MBean Server that can be accessed and manipulated from an AXIS-enabled remote console. Under this approach is possible to monitor the status of JMX-enabled services and components through an AXIS (SOAP) customer interface. The MBean server tracks global information and statistics about Web services. In order to do this, a Web-based interface was developed, which displays this data based on a hostname and port pair specified in a simple form embedded in a servlet. Collectively, this functionality represents the direction toward active management of JMX-enabled data and application resources over a standard AXIS (SOAP) interface. This illustrates an approach to managing Web services by instrumenting AXIS through the use of handlers to provide a JMX-based systems management interface. In this case, AXIS handlers were developed and added to the handler chains of our various Web services to allow statistics about those services to be gathered.

The JMX MBean Server which tracks the service statistics is instantiated globally within the application server’s JVM, allowing statistics to be tracked across all instrumented Web applications. Finally, for each Web service deployed by BROSEMWEB, the following statistics are tracked: (1) Current state, (2) Total number of managed SOAP services deployed, (3) Total number of RPC calls to all managed services combined, and (4) Total number of successful invocations, (5) Number of failed invocations (requests received by the server but resulted in an exception), (6) Average response/transaction time for successful requests.

To illustrate the functionality of BROSEMWEB, we describe next an e-Procurement multi-level scenario that integrates several products and services among customers, suppliers and providers that has been already implemented.

4. Case study: an multi-level e-Procurement scenario

Due to quantity of suppliers that are involved in a supply chain, BROSEMWEB can be used in multi-level e-Procurement process (Fig. 4). BROSEMWEB is presented in this section to demonstrate how it facilitates the discovery of Semantic Web Services that are offered by different enterprises that sell electronic components. We have analyzed the following two scenarios:

a. The enterprises sell on-line electronic components. The enterprises have registered their products and their business processes as Semantic Web Services in BROSEMWEB.

b. A potential customer (enterprise) starts a procure products by requesting a purchase order.

In this scenario, we described the fundamental problem of determining how a customer can discover and invoke the Semantic Web Services available to carry out e-Procurement?

On the other hand, we assume that the business processes of registered enterprises in our architecture are based on the commercial behaviors described in RosettaNet PIPs. But, we do not assume that all suppliers use the same data fields for product descriptions and follow the same protocol for their interactions with customers. Four types of scenarios of responses are analyzed:

1) The customer’s request cannot be processed, because it is ill-formed and BROSEMWEB does not understand it. Some factors, such as lack of parameters or invoking a semantic web service with a wrong operation name, produce an ill-formed request. In this case, an error message indicating that the request cannot be processed is returned.

2) No supplier is found for the requested product. The hybrid architecture returns an empty list indicating that no supplier can supply the requested product. This situation is derived from two factors: (1) the requested product is not registered in BROSEMWEB and therefore suppliers are not available, and (2) the requested product is registered but is not associated with a supplier.

3) A supplier for the requested product is found. BROSEMWEB returns a list of the enterprises that appear as the product suppliers. This is the better case because the requested product is registered and is associated with a supplier. In this case, a list of suppliers that offer the requested product in their stocks is displayed.

4) A supplier is found but the product is not available at that time. In this case, BROSEMWEB may search in obtaining such a product from the registered suppliers. This scenario occurs most often in the process of supplying products to the enterprises, due to lack of inventory management.

The steps and the whole e-Procurement business process based on the fourth kind of response are shown in Fig. 5.

The proposed solution for scenario fourth (above mentioned), is based on the use of business processes patterns described as BPEL workflows, after an event-based subscription pattern that occurs.

this is used to obtain a list of suppliers offering the requested product in sufficient quantities. The event-based subscription pattern is explained as follows: BROSEMWEB creates new instances for both service and subscription registries (Steps 1–4). This step is an initialization phase in which BROSEMWEB is ready for listening customer’s requests. The customer submits a request by sending a SOAP message containing the product description (Step 5). This request corresponds to the RosettaNet PIP 2A5 (Query Technical Information). The SOAP message analyzer extracts the product description to be sent to the discovery service. The query formulator builds a query to determine the qualified suppliers.
The query formulator transforms the product description into SQL sentences and builds a query to the service registry. The query is executed and the response is a set of OWL-S documents of candidate suppliers (Steps 6–9). Each OWL-S document represents the RosettaNet PIP 2A5 from available suppliers and for each one, the access point, operations, messages and parameters are retrieved through the OWL-S document analyzer. Then, the binding service identifies the type of communication protocol specified in each OWL-S document and invokes the semantic web service of each candidate supplier (Step 10–11). BROSEMWEB receives the supplier’s response (Steps 12–13). Then, the SOAP message analyzer determines which of the four types of responses mentioned before was included in the message. Whenever the response corresponds to the fourth case, an execution event is triggered by asking the customer if it is willing to subscribe for a product supplier when it becomes available (Step 14). If the customer accepts, BROSEMWEB uses the publish/subscription mechanism within the subscription registry, publishing the customer’s requested product description and generating a subscription-Key that will be returned to the customer (Steps 15–20). Then, the customer invokes the subscription service by sending a SOAP message containing the subscription-Key. In this case, the customer will be waiting for an answer (Step 21). During this wait, BROSEMWEB requests a corresponding subscription-Key from the supplier by sending the customer’s requested product description (Steps 22–23). The supplier stores the product description and generates a subscription-Key as a response to the request (Steps 24–26). Next, another execution event is triggered by invoking the supplier’s subscribe service and waits for a supplier’s answer (Steps 27–29). During this wait, the event-based subscription pattern in the second level of e-Procurement process begins when a supplier wants to find providers for a product description. Therefore, the process is the same but the partners take different roles, i.e., the supplier acts as a customer and the supplier acts as a supplier of BROSEMWEB. When the supplier’s response is returned to the second level of e-Procurement process, the architecture analyzes it and retrieves the useful information about the requested product. With this information, BROSEMWEB is able to send a response to the supplier’s subscribe service request. Here the second level of e-Procurement process is completed. In a similar way, the supplier will answer to the subscribe service request and his wait will finish (Step 58–59). The architecture is able to answer the customer’s subscribe service request and as a consequence, the customer’s wait will finish and the customer is getting the information about his requested product (Step 60). A screenshot of products selection is shown in Fig. 6. The information about a requested product by the customer is shown in Fig. 7. At this point, the customer is already able to select the quantity of the requested product. Once selected, BROSEMWEB makes a query to the service registry to locate the URL where the RosettaNet PIP 3A4 (Request Purchase Order) is located to obtain and analyze the semantic web service specification.

Next, a graphic user interface of the Web semantic service specification is displayed, enabling the visualization of the activities involved in the purchasing order process. The customer is then asked to provide the information required to complete the purchase. This graphic interface is shown in Fig. 8. Upon completion, the Web service corresponding to the RosettaNet PIP 3A5 is invoked (Query Order Status) to verify that the purchase was successful. Finally, the results to the user are displayed.

So far, we have shown only one example that illustrates the business processes integration by using BROSEMWEB. However, a wide variety of other cases studies involving several optimization criteria have been developed and tested such as distributed shopping, shopping with the minimum delivery time, lowest price, specified quantity, and finally with no constraints too.

We believe that our approach may lead to new forms of technological infrastructure in e-Procurement scenarios centered on the benefits provided by BROSEMWEB. By using BROSEMWEB, small organizations can automate their business processes involved in e-Procurement environments without making large investments in software development and deployment.

5. Evaluation of results and performance of BROSEMWEB

The functionality of BROSEMWEB is encapsulated in Semantic Web Services and coarse grain were developed which themselves
accept all necessary parameters and information. In this context, semantic technologies provide a perfect scenario to access information which can come from different type of sources. The structure knowledge which is provided by semantic repositories allows an exchange of information in a quickly way than other type of services. Also, the type and amount of information which can be accessed through the use of semantic technologies is getting bigger and bigger through the implantation of Linked Data. The new trend of information storing which is implanted in several organizations. A good example of the vast amount of information which can be accessed is the last graphic of LOD Cloud.5 Going more in depth, the use of semantic technologies and large data repositories as the ones which are supported by Linked Data will allow the discovery of new knowledge through the use of reasoners, being a perfect scenario for the application of BROSEMWEB. Hence, the goal is to minimize the number of requests that user makes in order to accomplish a set of tasks. This will ensure minimal efforts due to network latency, system I/O and thread/process wait states that when aggregated with multiple requests can result in significant delays. Furthermore, the Document/Literal messaging style was implemented for developing the Semantic Web Services set. Document/Literal results in smaller and less complex messages: the XML data in the body of the SOAP message does not have to be wrapped with a method name element and no data type attributes are inserted into the XML elements.

The evaluation of BROSEMWEB was conducted from two different points of view: validation of the user’s requirements and the system functionality. These tasks were planned following the next stages: (1) Data collection, (2) assembled a panel of experts, (3) Selection of the tool or strategy, and finally, (4) Data analysis and observation. The first evaluation was fulfilled in the first stages of development. The objective of this effort was focused in clearly define the system requirements with a single purpose: to maximize the system functionality or usefulness with available resources. In order to define the user’s requirements, the team behind BROSEMWEB extracted the common requirements reported in technical literature [1,4,9,11,14,22,26,30]. The requirements under evaluation were: (R1) B2B collaboration, (R2) Management of business processes, (R3) Monitor business interactions, (R4) Semantic Web Services, (R5) Event publish/subscription mechanism, (R6) Messaging service, (R7) Repository Mechanism, and (R8) Semantic Web Service Discovery. Once the main requirements were identified, then a panel of 7 experts from different fields such as industrial engineering, computational sciences, and even active managers were invited to rank these features according their subjective perception about e-Procurement. A previous description and definition of each feature was provided and discussed among the members panel to reduce ambiguity. Then the Pugh’s concept selection process was employed to select the most important requirements [33]. The Pugh’s selection process has been employed to select concepts or requirements in software [34], design [35], among other domains. A methodology was proposed in [33]. The main steps are: (1) Define design requirements and constrains, (2) Use the same level of detail in every design alternative or requirement, (3) Establish evaluation criteria, (4) Select one design or requirement as reference. All possibilities should be compared against this initial model, and (4) Deploy this process in blackboard or any other mean that guarantees that each participant has the same view of the concepts. Three symbols are used to evaluate a set of features: (+) means “better than or preferable”, (−) means “worse than or less desirable than”; and ($) means “same as” or “very similar than”. Next table summarizes the panel of expert’s perception.

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According to this evaluation, the last two features have a lower level of importance and they will not be considered in the system. Once a ranking was obtained, this information was combined with reported requirements, next functions were considered as fundamental: B2B collaboration, Management of business processes, Monitor business interactions, Semantic Web Services, Event publish/subscription mechanism, and Messaging service.

The second dimension evaluated was the system functionality. This evaluation was carried out through a set of performance indicators extracted from the server. As described in Section 3.2, JMX MBean Server collects several statistics, which are globally instantiated within the application server’s JVM. This information enables statistical tracking across all instrumented Web applications. Among the most important indicator are: current state of the system, total number of managed SOAP services deployed, total number of RPC calls to all managed services combined, total number of successful invocations, the number of failed invocations (requests received by the server but resulted in an exception), average response/transaction time for successful requests, available number of message services, the number of tested semantic web services, and the number of mechanisms for monitoring interactions.

Among these performance indicators, one demands special attention: the total number of successful invocations. In order to evaluate this indicator, 100 simultaneous requests were launched in the system. This request was launched 5 more times to observe consistency in response. With this information a goodness of fit test was deployed. The goodness of fit evaluates the discrepancy between observed and expected values. This test is useful to evaluate performance in several models from ecological modeling to computational statistics [36,37]. The methodology to execute this test is described in [38]. In this context, the goodness of fit test was useful to identify a probability function to represent the expected delay in the response time for an increasing number of simultaneous requests. This function could be represented with a Beta distribution, which can be used empirically to estimate the actual distribution before much data is available. Beta distribution is useful to represent service time, phase derivatives in communication theory, size of progeny in bacteria, dissipation rate in breakage models, among other applications [39].

Available data shows a Beta distribution with a minimum of 725 ms, a maximum of 1696 ms, a p = 0.9327 and q = 1.10. Six classes were used in the test. The results obtained in the test are congruent with the observed response time in the system. The accuracy of fit was set as 0.0003 and the level of significance defined as 0.05. Available data shows that the probability to only have successful invocations is near to 99%. Mora data is necessary

5 http://lod-cloud.net/.
to determine the number of simultaneous invocations that should be present to considerably overcome the maximum time obtained in the test.

6. Future directions

As future directions, we are considering to incorporate collective intelligence. Nowadays, Collective Intelligence (CI) is an active field of research based on the principle that each person knows about something, and therefore nobody has the absolute knowledge. For this reason, it is essential the incorporation and participation of the knowledge of every stakeholder in order to capitalize the collective intelligence dimension. By using CI, BROSEMWEB could be responsible for managing the existing information, so the business partners involved in the e-procurement process can obtain a useful mean to create and share knowledge. In Collective Intelligence there are mechanisms that can be implemented into BROSEMWEB, these mechanisms can be: (1) Reputation and (2) Recommendation. Knowing the supplier’s reputation is what makes us to bid money for a product, which we know through the comments and consideration of previous buyers. BROSEMWEB could display a description of each product and service where the supplier’s reputation can be visualized. In the case of recommendation, BROSEMWEB could suggest other products and services that might be interesting for the providers/suppliers. The recommendation of suppliers can be based on a comparison of the product price, transportation cost, delivery time and the product gap of each supplier. Finally, incorporating a recommendation system BROSEMWEB can track the user’s navigation within the Web site taking into account what has been bought in the past, products that have been qualified, those are available in the shopping list in order to determine what else might be of interest. Also, we are considering incorporating multimodality to BROSEMWEB with the aim of developing a mobile version. Multimodal interfaces are required since the limited input capabilities of mobile devices (small screens and slow input methods). In this sense, multimodal interfaces can improve interaction for different users and usage contexts, increasing performance, stability, robustness, expressive power and efficiency of supply chain activities.

7. Conclusions

As can be draw from the content of the paper, SCM is still an important problem to be addressed due to its complexity. However, after the results provided, authors are satisfied with the appliance of the hybrid architecture presented, borrowing features from SOA and EDA. The architecture of BROSEMWEB platform provides a comprehensive framework for the development of business integration, collaboration, and monitoring in SCM scenarios. The platform provides a set of Web interfaces where different enterprises can offer their products and services in SCM scenarios. The addition of Semantic features, concretely, Linked Data capabilities and the possibility of extract relevant information from Linked Data datasets generates as result a global improvement of the platform in several ways such as scalability, data availability and available amount of information. The semantic features are part of the mechanisms offered by the platform which includes the ability of publishing and discovering the business process provided by enterprises.

SCM is an important yet difficult problem to be addressed in its full complexity. However, we believe that hybrid architecture, borrowing features from SOA and EDA, may provide the fundamental structure in which the solutions to the diverse problems that SCM conveys can be accommodated. In this paper, we have described an architecture called BROSEMWEB that provides a comprehensive framework for developing business integration, collaboration and monitoring in SCM scenarios. BROSEMWEB provides a set of Web-based interfaces where different enterprises can offer their products and services in SCM scenarios. To achieve this, BROSEMWEB offers mechanisms to publish and discover the business process provided by enterprises. Enterprises must register their business processes described as Web services to enable to potential customers to integrate their processes with them through BROSEMWEB.

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References


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