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ABSTRACT

Web service, as an emerging technology, is being more and more widely adopted on the Internet for electronic business. The emergence of web service greatly facilitates business process management and reengineering. This paper develops a conceptual architecture for workflow management system based on web service infrastructure. The proposed architecture fully explores the benefits offered by web services by providing a flexible, dynamic and adaptive environment for workflow processing. Customer satisfaction and competitive advantages are supposed to result from systems based on the architecture.

Keywords

Workflow management, web service, software agent.

INTRODUCTION

With the development of information technology, the Web, which was once solely a source of information, is evolving into a provider of services. Web service is an emerging technology to enable the service-oriented architecture on the Web. According to the definition by World Wide Web Consortium (W3C), Web Services are programmable, distributed application components accessible on the web using solely standard Internet protocols. Infrastructures and standards are currently being developed to support the application and implementation of Web services, among which the most important are Web Services Definition Language (WSDL), Simple Object Access Protocol (SOAP) and Universal Description, Discovery and Integration (UDDI). Web service is believed to have great impact on the way business is conducted within and between organizations, it represents a revolution in e-business and opens the doors for new business opportunities. Some enterprises provide tools to web service-enable their legacy systems, encapsulate organization's functionality within appropriate interface and expose as Web services. So it allows different enterprise systems to be connected using lightweight protocols and XML-based technology (Fremantle et al. 2002). Web services technology enables dynamic e-business, which is the dynamic adaptation of business processes and associated systems to support changing business strategies and tactics. Business process management or process reengineering has long been a research area in the field of information systems, it studies technologies, mechanisms and policies to streamline the business process and enhance efficiency and effectiveness in business performance. Recent research effort of process management focuses on workflow system, which is defined as information system to automate a business process through the use of software (WFMC 1999). Web service technologies offer great opportunities to meet the requirements of dynamic and fast-changing business. However, currently Web service related researches concentrate on technical issues of service infrastructure, not conducted at the level of business process management. There has been no systematic research on process management based on the infrastructure of Web services. In this paper we propose a web service oriented workflow management system (WSWfMS) to fill this gap. The system provides a unified view of workflow management in the context of distributed, autonomous and heterogeneous Web services. It uses AI technologies to explore the Web semantics to perform process management in a more efficient and flexible manner.

RELATED WORK

Workflow Management System

According to the Workflow Management Coalition (1999), a workflow is defined as the automation of a business process during which documents, information or tasks are passed from one participant to another for action, following a set of procedural rules. While a business process is a set of one or more linked procedures or activities which collectively realize a business objective or goal, normally within the context of an organizational structure defining functional roles and relationships. A workflow management system (WfMS) is a system that defines, creates, and manages the execution of workflows through the use of software. Previous researches on workflow management focused on dynamic work distribution (Kumar et al. 2001), enhancing workflow with Quality of Service (QoS) components (Cardoso 2002), and knowledge-based exception handling (Kumar and Zhao, 1999; Klein and Dellarocas, 2000). These approaches enable dynamic work allocation and automatic exception handling by agents to reduce the need for human intervention, which helps build workflow systems that are more flexible and fault tolerant.

Semantic Web Service

While in some cases web services may be used in an isolated form, it is normal to expect web services to be integrated as part of workflow processes. There are a great number of web services accessible, so composition of workflow of services differs from the design of traditional workflows, in terms of the number of tasks available to the composition process, in their heterogeneity, and in their autonomy. The researches on web semantics have been focused on discovery, composition and interoperability of web services. In order for agents to select services in a context-sensitive manner, they must be able to discover services based on semantic description. Some research projects use DAML-S for service description (Ankolekar 2002), McIlraith et al. (2001) described service attributes in DAML-S, so they can be discovered by agents based on functional requirements. Cardoso and Sheth (2002) adopted the concept of Quality of Service (QoS) in workflow management, and studied service discovery on both functional and operational requirements to integrate it into workflow to meet specific requirements of business process. They proposed an operational metrics with three dimensions: task response time, cost and reliability, and also developed search algorithms to compare workflow task requirements with service profiles syntactically, semantically and operationally, so web services with enough multi-dimensional similarity to the task can be found and integrated into the workflow model.

For web service composition and interoperation, outputs of one service are mapped to inputs of next one in the flow sequence. Heterogeneity is a problem to be solved because web services may use same or different ontology. Heterogeneity has long been a hot topic in the research of web semantics, digital library, and database systems. The issue of how to integrate heterogeneous data sources has been handled by using metadata, intermediate standards or external mediation (Paepcke et al. 1998). Cardoso and Sheth (2002) developed some mechanisms to perform the mapping through similarity comparison. Other recent research efforts suggest to overcome data and ontological heterogeneity through metadata based shared ontology (Kim 2002), mediation (Firat et al. 2002; Moulton et al. 2002) or integration knowledge (Kazakos et al. 2002). These researches provide infrastructure and lay technical foundation for resolution of semantic difference among web services.

CONCEPTUAL MODEL OF WSWFMS

The WSWfMS provides the workflow management functions, including workflow planning, creation, execution, monitoring and exception handling. It has interface for process definition and system administration. Several of commercial workflow systems provides workflow engines that support WSFL or BPEL4WS, but the workflow schema need to be predefined, so they are static and lack flexibility. The WSWfMS is flexible and context-dependent to meet the specific requirements of business situation. It has following characteristics:

- Dynamic: the composition of workflow activities is dynamic, instead of static. The workflow description (script) is in the form of sequence of web services, and composition of services depends on business context, not predefined, so it may varies from transaction to transaction.
- Flexible: the system is flexible enough to deal with uncertainty in the online environment. Exceptions or even errors may occur in the service providers or the network infrastructure, so the system is fault tolerant and continue workflow progress in even unstable environment.
- Adaptive: the system behavior is adaptive. Although the generic business processes or workflow schema are defined by system managers, creation of workflow instances is adapted to business context to meet specific requirements. The system has learning capabilities through evaluation and interaction with user, so it is self-adaptive and gradually refines its performance.

Knowledge of WSWfMS

It is generally agreed that knowledge about business process, web service, and exception handling should be captured in the system.

- Business process knowledge: is knowledge about generic business processes and their constituent tasks. A generic business process (e.g. the process of customer purchase order processing) is defined as a sequence of tasks and the relationships between them, including control link and data link.
- Web service knowledge: is web service profiles. A web service specification includes following items: name; URL; Port type to indicate the role played by the service, e.g. shipper, vendor, etc; textual description of the service function; inputs to the service; outputs from the service; binding information; operational metrics of the service, including time, cost and reliability.
- Exception handling knowledge: knowledge about exception detection, diagnosis and resolution, including exception specification, handler specification and rules for handling.

The Conceptual Model of the System

The architecture of the WSWfMS is based on the notions of software agents that were presented by Geneserth and Ketchpel (1994). These agents interact with the user and among themselves using messages. Each functional agent has access to and maintains the necessary knowledge for the activities performed by it. The architecture is composed of five agents, knowledge bases, and web services as external resources on the Internet. UDDI is the public web service registry, all published web services have description in WSDL in the UDDI registry.

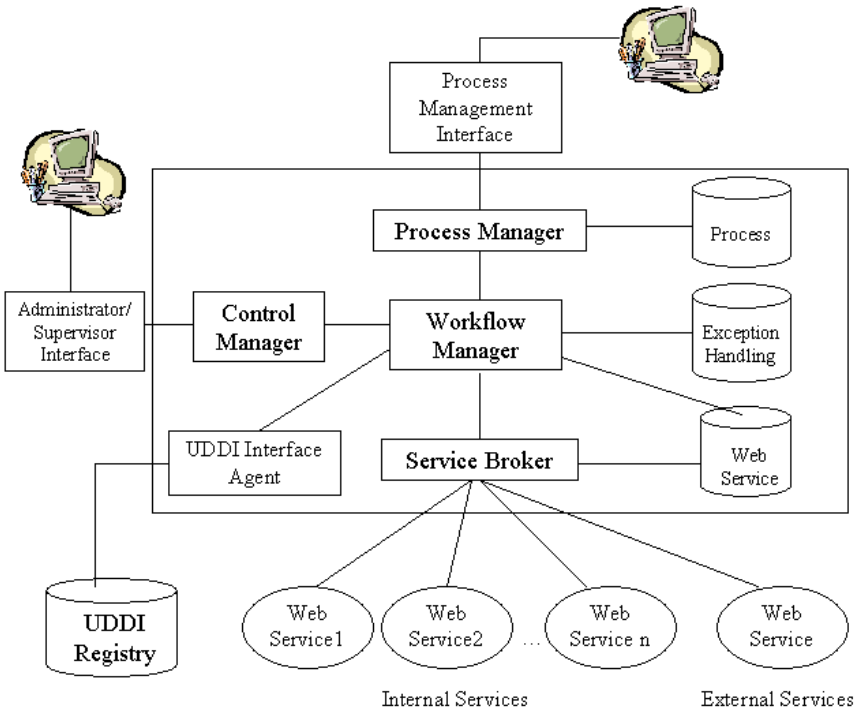

Figure 1. Architecture of WSWfMS

Workflow Manager performs the function of workflow enactment service. It creates workflow instance, schedules tasks, executes and monitors workflow instance, and also handles exceptions that occur in the process of execution. Control Manager handles the interaction with the system administrator or supervisor. It manages the process administration and monitoring tools, receives and interprets commands from the administrator to start, stop, suspend and resume workflows. Process Manager handles the interaction with the business process manager. It manages the business process definitions and the process analysis, modeling and definition tools, supports the user to define new business processes or modify existing business processes. Service broker acts as interface between the workflow manager and web services, it receives service request from the workflow manager, forward the request to corresponding web service for execution, and then sends response from web service back to the workflow manager. UDDI Interface Agent serves as the interface to UDDI on the Internet, it accesses the UDDI to get appropriate service if no service profile in the system knowledge base meets the particular transaction requirement. Internal services refer to the web services that are inside the organization, different functional units may appear as different

web services that perform specific functions. It's reasonable to believe they may adopt same ontology. External services refer to services available on the Internet to which the organization may outsource its business functions. It's highly possible that they adopt different ontologies from each other and from the ontology used by the organization.

Structure of the Workflow Manager

The workflow manager is the central part in the system, it performs the core functions of workflow management. The primary function of the Workflow Manager is to manage workflow instances. It creates workflow instance according to business context or requirements; executes workflow instance and monitors the status; if exception occurs, handles the exception to re-gain normal operation. A business process is abstract and indicates what tasks to do to fulfill the process; but a workflow instance is a sequence of web services with parameter values, and it specifies how to complete the particular transaction. In the context of web services, the roles in workflow are performed by different services and work distribution is actually selection of appropriate services.

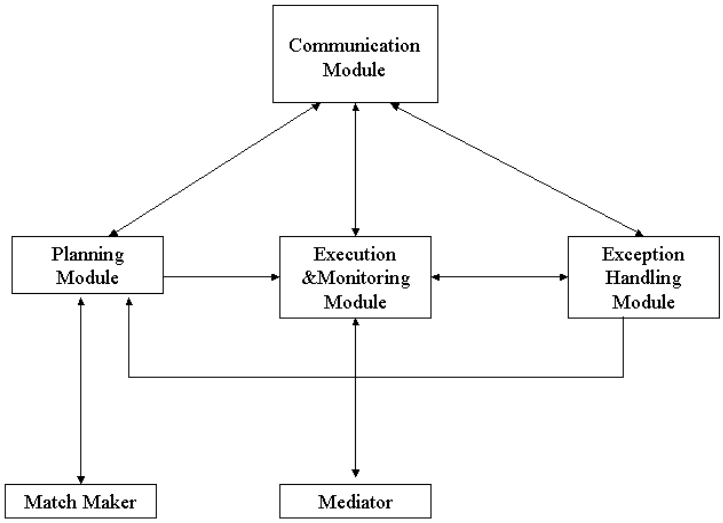

Figure 2. Structure of the Workflow Manager

The workflow manager contains six modules:

- Communication module – for communication with other agents in the system, it accepts and interprets message from other agents in KQML.
- Planning module – creates workflow instance to meet the specific transaction requirements. Based on appropriate process definition it creates workflow instance with specific work requirements, e.g. order type, quantity and operational requirements (time, cost, reliability). Mapping from business task to service is done through the Match Maker. If no web service profile in the knowledge base can meet the business requirement, UDDI registry should be accessed through the UDDI Interface Agent to find proper service, and the service information from UDDI is added to the web service profiles in the system knowledge base. Newly built workflow instance is stored in the knowledge base, so it can be retrieved for use in similar contexts. An intra-organizational workflow includes only internal services that represent organizational departments, so it is relatively constant and static. An inter-organizational workflow may include internal services and external services that represent outside organizations. In an inter-organizational workflow scheme, the part to link internal services is relatively constant because they represent the core competency of the company, but the part for external services may be quite dynamic and changeable since they represent the company's business partner, and the relationship might be ad hoc and temporary. To make the planning more effective, the constant parts in a workflow can be decided first, then choose outside services that are appropriate semantically, syntactically and operationally to fit into the other parts in the workflow.
- Execution & monitoring module – takes the workflow instance, monitors and completes its execution. It executes the workflow instance that is composed of a sequence of service operations step by step. It prepares an action for execution by setting up a context (including the results of previous actions, etc) for the action, if heterogeneity exists between service operations that have data exchange in the sequence, it addresses them to the mediator for resolution. It monitors the action by optionally providing the associated computation limited

resources, for example, the action may be allowed only a certain amount of time and if the action does not complete before that time is up, the computation is interrupted and the action is marked as having failed. It evaluates after execution of each action, if the outcome is not as intended, it reports exception and activates exception handling. And the monitored service performance is used to update the operational metrics of web services.

- Exception handling module – takes over control when exception occurs, and helps to recover from it. Whenever the required service cannot be found, the service is out of work, or the output is not as intended, this module will automatically invoke an exception handling routine, which might call to re-execute the action, or invoke a re-planning process, or simply wait for a particular time interval before re-trying accessing the service. If the exception is not anticipated and no appropriate handler is found in the knowledge base, then it will be referred to the system administrator/supervisor for intervention. Their response is recorded to update the knowledge base of exception handling.
- Match Maker – it performs automatic web service discovery. It compares task requirements with service profiles in the knowledge base, to find web service that is closest to the task requirements semantically, syntactically, functionally and operationally.
- Mediator - it handles conflict of heterogeneity between different web services. If web services which have information exchange in the same workflow use different ontologies, mediation is needed to resolve the conflicts. Shared ontology is adopted for mediation between the different web services.

VALIDATION OF THE CONCEPTUAL MODEL OF WSWFMS

The proposed model is flexible, dynamic and adaptive. It fully explores the advantages that provided by web services. In this model, business process reengineering can be easily realized through dynamic composition of web services and quickly adapts to the changes in business context to provide most values to customers and gain competitive advantages for the organization.

We use a business example to illustrate the characteristics of the model. Figure3 shows the business process for a retailer, it's an inter-organizational process which contains three participants: the retailer, the manufacturer and the shipper. These three partners cooperate as a virtual enterprise to fulfill orders from customers.

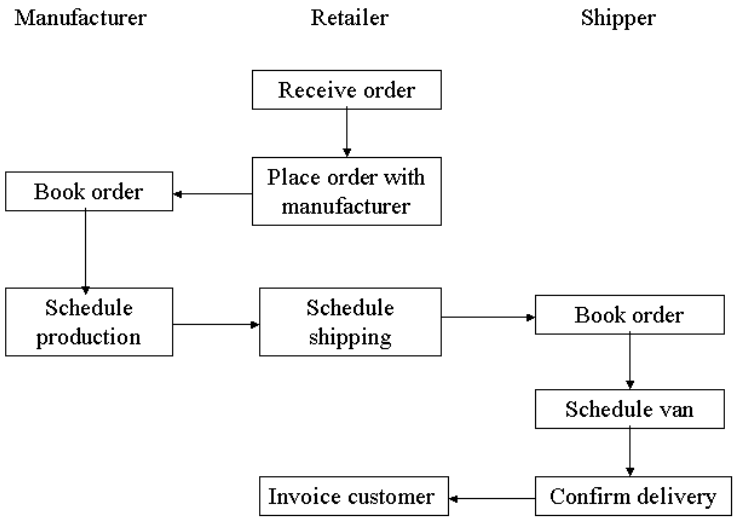

Figure3. Order Fulfillment Process of a Retailer

The process definition contains a sequence of activities that are played by different roles: receive order, place order with manufacture, book order (manufacturer), schedule production, schedule shipping, book order (shipper), schedule van, confirm delivery, invoice customer. The process definition provides a generic model of the business process, which is a sequence of activities and the order in which they are executed.

There are some workflow models based on the process definition, for example, workflow for computer order processing, workflow for garment order processing, etc. Each workflow model is a sequence of web service

operations, with data links showing data exchange between them, and control links showing temporal constraints among them. In workflow model, specific web service operations replace abstract tasks in process definition.

In a routine situation, for example, when the retailer receives an online order for a Dell computer, the planning component in the workflow manager analyzes the order, chooses an appropriate workflow model (workflow for Dell computer order processing), and creates a workflow instance for execution. The execution & monitor component executes the instance step by step through invoking corresponding web service operations through the service broker. For example, it invokes local service operation "receive order", and "place order with manufacturer", then invokes the web service of Dell company, after receives confirmation from Dell, it executes "scheduling shipping", and then invokes the service of a shipper, after get delivery confirmation from the shipper, it executes "invoice customer" to complete the order. Invocation of web service operations are performed through the service broker, which transfers service invocation to corresponding web service, so the workflow manager does not consider the specific location of the services and binding to them. The execution is monitored and the history of the instance is recorded, if any exception occurs, corresponding handler will be activated, for example, if the shipper service is temporarily down and the workflow manager does not receive confirmation from it in specific time period, an exception is reported and the exception handling component handles it by choosing another shipper and re-executing this step. If the exception can not be resolved this way, for example, no alternative shipper service can be found to re-execute the step, the exception handling component handles it by re-planning and find another process that can reach the same goal; if the exception still can not be resolved, it will be addressed to the control manager, and system administrator's intervention is needed.

If existing routine workflows do not meet requirement of a particular order, for example, if the retailer receives an order with the deadline in only three days, according to the operational metrics of existing workflows, none of them can fulfill the order in such a short time. To handle this case, the planning component retrieves the business process definition and generates a new workflow model based on the process definition, it sends requests to the match maker, which maps the requests to services that fit them most from the service profiles. The new workflow is composed of web services that are different from those in old ones, for example, in the new workflow, UPS replaces shipper in the old ones to reduce the shipping time, so that customer can receive ordered computer within three days. The new workflow is stored in the system so it can be retrieved for use in similar business context later.

After execution of each workflow instance, an evaluation happens to it, and the performance of each service in the workflow is recorded in the operational metrics.

The business process manager can define new process or modify existing processes, he may do this using graphical definition tools, and the defined or modified process will be automatically transformed by the process manager to update the knowledge base of processes. The action of process definition and modification can be initiated by the process manager, who has the desire to improve business performance, following changes in business strategy and tactics, or it can be pressed by the workflow manager, which has to adapt to changes in business situation, and find inadequacy in current process models.

The system administrator or supervisor monitor and control ongoing workflow instances through the control manager, which reports status and exceptions of workflow instances to the administrator, receives command and operates on the workflows on behalf of the administrator.

EVALUATION OF THE WSWFMS MODEL

The design of the WSWFMS model is based on the workflow reference model, but it includes some features to extend the reference model so as to meet the requirements of web service infrastructure. The purpose of the design is to generate a paradigm for workflow management in web service context to fully realize the advantages provided by web services.

WSWFMS vs. Workflow Reference Model

Compared with the traditional workflow reference model, WSWFMS has more flexibility and adaptability. Currently most of commercial workflow management systems are based on the workflow reference model, the workflow definition is static, change in process is relatively difficult and time-consuming due to the rigid underlying structure. WSWFMS is much more flexible, in WSWFMS composition of workflow is dynamic and easily adaptive to business context. So WSWFMS explores the advantages of web service to gain competitive edge for the company. WSWFMS greatly facilitates virtual enterprise by making function outsourcing and process integration much faster and easier.

WSWFMS vs. Other Web Service Based Process Management Systems

Compared with WSWFMS, other web service based process management systems do not provide a unified view of business process management in web service context. They just focus on a few aspects respectively. For example, the model proposed by McIlraith et al. (2001) focuses on agent-based discovery and composition of web services;

the model by Leymann et al. (2002) focuses on process definition and workflow modeling; and the model by Cardoso and Sheth (2002) focuses on operational metrics and discovery of web services. WSWFMS includes all of the important components required for a complete service based workflow management system, including process definition, workflow modeling, controlling, planning, execution, monitoring, exception handling, service discovery and mediation. It provides guidelines for further research in this area and implementation of business process management system based on web service architecture.

Limitations of the Proposed Model

Limitations of the proposed model should also be noticed. WSWFMS is a knowledge-based system, in which the adaptability and flexibility depends on availability and sufficiency of knowledge possessed by the system. Some types of knowledge, for example, the operational metrics of services, are accumulated through the operation of the system. So, at the beginning the system may not perform well enough as expected due to lack of knowledge. But the performance will improve step by step through the process of system learning.

CONCLUSION

It is believed that web service will impose great impact on the way business transactions are conducted. This paper presents a conceptual model of business process management on the infrastructure of web services. The model provides flexible, dynamic and adaptive solution to business process management in the new technology context, and presents the basic knowledge and functional components of the system. Future research can be done to further investigate the structure of the components and the performance of the model.

REFERENCES

1. Ankolekar, A., Huch, F. and Sycara, K. (2002) Concurrent Semantics for the Web Services Specification Language DAML-S, *Proceedings of the Fifth International Conference on Coordination Models and Languages*, York, UK, April 8-11.
2. Cardoso, A. (2002) Quality of service and semantic composition of workflows, Ph.D dissertation, Department of Computer Science, University of Georgia.
3. Cardoso, J. and Sheth, A. (2002) Semantic e-workflow composition, *Technical Report #02-004*, LSDIS Lab, Computer Science Department, University of Georgia, Athens, GA, July 2002.
4. Freemantle, P., Weerawarana, S. and Khalaf, R. (2002) Enterprise Services, *Communications of the ACM*, Vol.45, No.10, October.
5 Geneserth, M. and Ketchpel, S. (1994) Software agents, *Communications of the ACM*, Vol.37, no.7, pp.48-53.
6 Kazakos, W., Nagypal, G., Schmidt, A. and Tomczyk, P. (2002) XI3- Towards an integration Web, *Proceedings of WTIS 2002*.
7 Kim, H. (2002) Exploring the small-worlds of the semantic Web using meta-data based shared ontologies: Using structure and semantics to connect heterogeneous, local ontologies, *Proceedings of WITS 2002*.
8 Klein, M. and Dellarocas, C. (2000) A knowledge-based approach to handling exceptions in workflow systems, *Journal of Computer Supported Collaborative Work,* Special Issue on Adaptive Workflow Systems, January.
9 Kumar, A. and Zhao, J. L. (1999) Dynamic routing and operational controls in workflow management systems, *Management Science*, Vol. 45, Iss. 2, p.253-262.
10 Kumar, A., Aalst, W. and Verbeek, E. (2001) Dynamic work distribution in workflow management systems: How to balance quality and performance, *Journal of Management Information Systems,* Vol. 18, Iss. 3, p. 157-193.
11 McIlraith, S., Son, T., and Zeng, H. (2001) Semantic Web Services, *IEEE Intelligent Systems*, March/April 2001, p.46-53.
12 Moulton, A., Madnick, S. and Siegel, M. (2002) Context interchange mediation for semantic interoperability and dynamic integration of autonomous information sources in the fixed income security industry, *Proceedings of WITS 2002*.
13 Paepcke, A.; Chang, C.; Garcia-Molina, H. and Winograd, T. (1998) Interoperability for digital libraries worldwide, *Communications of the ACM*, Vol.41, No.4.
14 WfMC (1999) WFMC Terminology and Glossary, WfMC-TC-1011, Workflow Management Coalition.