A Semantic Grid Service Architecture for Computer Supported Cooperative Work in Multidisciplinary Design

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Abstract: - Although the current computer-aided design (CAD) and computer network technologies have laid the foundation for the emerging fields of computer supported cooperative work (CSCW) in multidisciplinary design, the heterogeneity of multidisciplinary design knowledge representation is still a major obstacle to sharing and exchanging multidisciplinary design knowledge for multidisciplinary collaborative design. To overcome this, an ontology-based service-oriented modeling approach is presented in this paper for distributed management of multidisciplinary design knowledge in the Semantic Grid, enabling to add semantics to grid services to endow them with semantic capabilities needed for their flexible deployment and reuse in multidisciplinary collaborative design. A service-oriented multi-agent system architecture is laid out in the Semantic Grid to address, in an open, loosely coupled and integrated manner, the life cycle of multidisciplinary collaborative design activities involved in publishing, discovering and reusing various grid services.

Key-Words: - CSCW; Collaborative design; Knowledge management; Multidisciplinary design; Ontology; Semantic Grid; Service-oriented modeling

1 Introduction

Due to current trends in the engineering design field towards multidisciplinary organizations that collaborate over internet to share and exchange multidisciplinary design knowledge, there is an increased need for multidisciplinary design teams to establish and maintain a computer supported cooperative work (CSCW) through effective communication, interoperation, integration, coordination and collaboration at the knowledge level.

Although the current computer-aided design (CAD) and computer network technologies have laid the foundation for the emerging fields of CSCW in multidisciplinary design, the heterogeneity of multidisciplinary design knowledge representation is still a major obstacle to sharing and exchanging multidisciplinary design knowledge for multidisciplinary collaborative design.

The recent popularity of Semantic Grid [1] has renewed people’s interest in building open, dynamic and adaptive systems, with a high degree of automation, which supports flexible coordination and collaboration on a global scale. Aiming at representing multidisciplinary design knowledge explicitly and formally and sharing it among multiple design agents, this paper describes a preliminary attempt at using Semantic Grid paradigm, especially service-oriented modeling approach for distributed management of multidisciplinary design knowledge, enabling to add semantics to grid services to endow them with capabilities needed for their successful deployment and reuse in multidisciplinary collaborative design. Formal knowledge representation in OWL format [2] extends traditional product modeling with capabilities of knowledge sharing and distributed problem solving, and is used as a content language within the FIPA ACL (Agent Communication Language) [3] messages to support cooperation among multiple design agents. A service-oriented multi-agent system architecture is laid out in the Semantic Grid to address, in an open, loosely coupled, and integrated manner, the life cycle of multidisciplinary collaborative design activities involved in publishing, discovering and reusing various grid services.

The effort in service-oriented modeling will remove one of the most commonly stated criticisms of the suitability of knowledge modeling used for knowledge management, due to the difficulty in building a single flawless model that contains all contextual information at different levels of abstraction. The proposed approach is viewed as a promising knowledge management method that facilitates the implementation of CSCW in multidisciplinary design for Semantic Grid applications.
2 Related Work

With the network rapidly proliferated all over the world, the past decade has seen a strong emphasis on the integrated product modeling to support collaboration in multidisciplinary design projects. Krishnamurthy & Law [4] proposed a three-layered data management model of versions, assemblies and configurations to store and maintain changes both across disciplines and through different levels of detail to support multidisciplinary collaborative design. By integrating VRML-based models with conventional CAD packages, Roy & Kodkani [5] described an open collaborative design environment to access and manipulate both geometric and technological content of the product model through a single internet interface. Bidarra et al. [6] employed a client-server architecture to develop a web-based collaborative feature modeling system that provides feature validation, multiple views and sophisticated visualization facilities. On one hand, the full functionality of an advanced feature modeling system is offered by the server. On the other hand, all desirable interactive modeling functionality is offered by the clients, ranging from display of feature model images to interactive selection facilities. Bohm et al. [7] adopted an XML data format to import and export the multidisciplinary design knowledge including artifacts, functions, forms, behaviors and flows from a design repository, which supports product design knowledge archival and web-based search, display of design model and associated tool generation.

However, aiming at providing information for human understanding not for machine processing, above modeling approaches cannot rigorously and unambiguously capture the semantics of exchanged multidisciplinary design knowledge, therefore prohibiting automated reasoning in multidisciplinary collaborative design environments.

The emerging Semantic Web [8] possesses a huge potential to overcome integrated product modeling difficulties over the web, by modeling the concepts in a knowledge domain with a high degree of granularity and formal structure including references to mutually agreed-on semantic definitions in ontologies. An example of the use of Semantic Web in integrated product modeling is configuration knowledge representations [9], which compares the requirements of a general configuration ontology with the logics chosen for the Semantic Web, and describes the specific extensions required for the purpose of communicating configuration knowledge between state-of-the-art configurators via Semantic Web languages OIL and DAML+OIL.

Convergence between the Semantic Web and another recent development in grid computing technologies [10] has seen grid technologies evolving towards the Semantic Grid [1]. The Semantic Grid is an extension of the current grid in which knowledge and web services are given well-defined meaning, better enabling intelligent agents to work in cooperation. Chen et al. [11] proposed a distributed knowledge management framework for semantics and knowledge creation, population and reuse in the Engineering Grid, better facilitating problem solving in computation and data intensive multidisciplinary design optimization involving fluid dynamics.

Notwithstanding the promising results reported from existing research work for multidisciplinary collaborative design, there has been little research using the service-oriented modeling approach to support CSCW in multidisciplinary design, especially, for Semantic Web or Semantic Grid applications. In addition, most existing approaches lack an ontology-based collaborative product modeling framework that supports a meaningful agent communication for CSCW in multidisciplinary design.

3 Service-Oriented Modeling to the Multidisciplinary Design Knowledge in the Semantic Grid

CSCW in multidisciplinary design is a very complex process, which involves plenty of product modeling tools and engineering knowledge from various disciplines at different design phases. However, these resources are often located geographically and represented in heterogeneous formats, makes effective capture, retrieval, reuse, sharing and exchange of knowledge a critical issue in a collaborative design development. The Semantic Grid infrastructure is utilized in this work to enable designers to carry out multidisciplinary collaborative design by seamless access to a state-of-the-art collection of product modeling tools and other knowledge resources around the internet.

In order to manage the multidisciplinary design knowledge in a manner that is explicit, formal, modular, extensible, interoperable, and yet comprehensible, an ontology-based service-oriented modeling approach to the multidisciplinary design knowledge in the Semantic Grid is proposed. It evolves along three consecutive layers, i.e., ontology modeling, knowledge reuse and knowledge
application layers, with diverse knowledge assets wrapped up as grid services to facilitate knowledge consumption and supply in the Semantic Grid (Figure 1).

3.1 Ontology modeling layer
Though various standalone product modeling services are able to describe and distinguish involved disciplinary-specific design knowledge while maintaining efficiency and computability in standalone, one-off product modeling environment, it cannot rigorously and unambiguously capture the semantics of exchanged multidisciplinary design knowledge, therefore prohibiting automated reasoning in multidisciplinary design environments. Towards composing and configuring various product modeling services to support distributed, multidisciplinary collaborative design, an ontological description to the multidisciplinary design knowledge is necessary to be exploited in the ontology modeling layer.

The need for rigorous and unambiguous description of multidisciplinary design knowledge can be summarized as a common ontological foundation that supports consistent conceptualization of distributed product design models. The key concepts of multidisciplinary design knowledge are represented as different domain ontologies at different design phases. Further, the multidisciplinary design ontology is built with the formal representation language OWL that is the most expressive semantic markup language up to date in the Semantic Grid.

An ontology registration service is used to register the ontology to an aggregate directory and to notify the directory service of the availability of the required ontology. An ontology transformation service is used to offer the grid infrastructure the capabilities to translate or map information from one ontology to another and to negotiate meaning or otherwise resolve differences between ontologies.

Fig. 1. Service-oriented modeling to the multidisciplinary design knowledge in the Semantic Grid

3.2 Knowledge reuse layer
The purpose of semantic descriptions to multidisciplinary design resources is to facilitate resource discovery, sharing and reuse, which is achieved by utilizing ontology query service and ontology reasoning service in the knowledge reuse
layer. The ontology query service provides query to the multidisciplinary design concepts, their properties and relationships in the underlying ontology repository, e.g., by returning the properties and relationships (such as parents or children) of a concept using OWL-QL [12]. The ontology reasoning service employs Description Logic (DL) reasoner to provide reasoning capabilities over various knowledge entities in the ontology repository. Any practical ontology DL reasoner such as Racer [13] can be applied to perform common ontological operations such as terminological and assertion reasoning, subsumption checking, navigating concept hierarchies, and so on.

3.3 Knowledge application layer
The development of knowledge applications will be facilitated by a set of generic application-level services such as semantic browsing service, inference service, and team collaboration service.

The semantic browsing service allows user to explore the multidisciplinary design ontology at the semantic level. A widely accepted ontology editor Protégé-2000 with the OWL Plugin [14] is used as the semantic browser to browse multidisciplinary design ontology, generate ontology graph, and classify new multidisciplinary design concepts and generate OWL source codes. The agent may reason with semantic markup written in OWL, with the Java Expert System Shell (JESS) [15] employed as an inference service. JESS is a rule engine and scripting environment written entirely in Sun’s Java language. The team collaboration service is used to provide collaborative work such as the status of collaborative team members, discussion minutes, meeting status, things-to-do list, project status, etc.

4 A Service-Oriented Multi-Agent System Architecture in the Semantic Grid
We seek to apply the Semantic Grid paradigm to develop a service-oriented multi-agent architecture as the backbone of the system prototype for multidisciplinary collaborative design (Figure 2), which mainly includes a UDDI service repository, an OWL-S service ontology repository, a domain resource ontology repository, a semantic service registry, a semantic service mapping mechanism, a service matchmaking mechanism, a JADE middleware and distributed application agents. The main functions of each component are described below.

As elaborated in the last section, a service-oriented modeling approach to the multidisciplinary design knowledge in the Semantic Grid is utilized in this work. All resources including a collection of product modeling tools, program modules and other knowledge resources act as grid services. Each grid service has a WSDL (Web Service Description Language) interface for service description, is registered in the UDDI (Universal Description, Discovery and Integration) service repository, and has a SOAP (Simple Object Access Protocol) listener for service implementation. SOAP is a standard for applications to exchange XML-formatted service descriptions over HTTP. WSDL, which is an XML-based interface definition language, describes what a Web service does, where it resides, and how to invoke it. UDDI is a standard for publishing information about Web services in a general registry.

Since WSDL only describes Web services as collections of operation names and XML Schema data type at a syntactic level, it is enriched by adding semantic information with OWL-S [16] service ontology in the proposed system architecture. OWL-S service ontology provides a core set of markup language constructs for describing the properties and capabilities of grid services in unambiguous and computer-interpretable form. As OWL-S service ontology does not provide complete vocabulary sets for describing specific grid services in various engineering domains, the domain-specific terms and concepts used in OWL-S to describe grid services are defined in domain resource ontology, e.g., multidisciplinary design ontology.

Once a grid service is semantically annotated, both syntactic and semantic information can be advertised in a semantic service registry via the UDDI service repository and OWL-S service ontology repository respectively, and that information can be used for service discovery. To support semantically enhanced service queries, a semantic service mapping between UDDI service repository and OWL-S service ontology repository needs to be built to make each grid service in the UDDI service repository have a corresponding semantic description in the OWL-S service ontology repository. The proposed approach differs from the traditional Web service system architecture, where UDDI service registry is the exclusive information resource.

The service matchmaking mechanism receives the request of the wanted grid service specification in WSDL, and cooperates with WSDL parser to analyze the structure of WSDL specification. Then it conducts semantically enhanced searches in the
OWL-S service ontology repository for the matching semantic service description. Finally the target grid service from the UDDI service repository can be found via the semantic service mapping between UDDI service repository and OWL-S service ontology repository, and returned for invocation.

The system architecture supports distributed design agents collocated within a collaborative virtual environment and semantically integrated within a FIPA-compliant Java Agent Development Environment (JADE) [17], which acts as a grid service consumer. JADE provides an agent middleware to support the agent representation, agent management and agent communication. For example, the control agent is responsible for managing operation on grid services, such as enhancement of system security and reconciliation of resource competition; the case base agent is responsible for distributed case base management; and the knowledge base agent manages the distributed knowledge hierarchy. An Agent Communication Language (ACL) enables agents to collaborate with each other by setting out the encoding, semantics and pragmatics of the communicating messages. The query request for multidisciplinary design ontology can be transformed from FIPA ACL messages into OWL-QL format, while the multidisciplinary design ontology with OWL format can be encapsulated into FIPA ACL messages to facilitate communication and sharing among multiple agents.

Fig. 2. A service-oriented multi-agent system architecture in the Semantic Grid

5 Conclusion

Being highly knowledge-oriented, CSCW in multidisciplinary design requires effective and efficient knowledge management tools. The proposed service-oriented modeling approach is intended to facilitate the distributed management of multidisciplinary design knowledge in the Semantic Grid, in order to populate the multidisciplinary design knowledge with ubiquitous semantic content and facilitate semantic interoperability among multiple agents. The service-oriented multi-agent system architecture is laid out in the Semantic Grid to address, in an open, loosely coupled and integrated manner, the life cycle of multidisciplinary collaborative design activities involved in publishing, discovering and reusing various grid services.
supports distributed agents collocated within a collaborative virtual environment, semantically integrated within the JADE middleware, and access to heterogeneous grid services.

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