Towards Semantic Grid in Construction Informatics

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ABSTRACT: Civil Engineering increasingly requires efficient Virtual Organizations of heterogeneous partners and facilities. Mainly four software architecture paradigms originating from the area of distributed computing have influenced the implementation of supporting software systems for Virtual Organizations: Grid, Peer-to-Peer, Agent as well as Web Service architectures. Each architecture paradigm accounts for different technical aspects that promote the realization of such software systems. The unification of these paradigms towards an integrated architecture has, to date, not been achieved. This keynote paper summarizes the state-of-the-art architecture paradigms and proposes elementary design issues for an integrating architecture. This architecture incorporates ontologies for regulating the communication and interoperability among different services. An application scenario finally demonstrates the usage of such an architecture.

1 INTRODUCTION

The analysis of different software paradigms originating from the research area of distributed computing constitutes one of the major research topics in today's construction informatics. The incentive for the investigation of these paradigms can be justified by the way of organizing up-to-date projects in civil and building engineering: a huge number of dispersed project partners and external experts collaborate in terms of temporary *virtual organizations* (VOs) aimed to accomplish a common goal. VOs also make use of *publicly available resources* such as services, autonomous checking algorithms, or hardware cycles, facilitating the concurrent execution of design activities or computations. Existing implementations of VO-like structures range from supporting planning activities in structural design (e.g. [Alda *et al.*, 2004], [Meißner *et al.*, 2003]) towards distributed, autonomous computations such as fatigue analyses ([Jelic *et al.*, 2005]).

As yet, existing virtual organizations have to tackle with problems like heterogeneous software installations, incompatible document exchange formats, untraceable resources, or coordination problems. Although the premises have been recognized and fairly understood, the above mentioned problems constrict the appreciation of virtual organizations in both scientific and industrial field.

This keynote paper outlines the four major influencing architectural styles from the field of distributed computing that are recently adopted for implementing VOs: agent-based, Peer-to-Peer, Grid as well as Web Service architectures (see section 2). A thorough inspection reveals commonalities and also differences among these notions. For instance, while agent-based architectures feature the *mobility* of code and data as a way for migrating computations, all other approaches rely on stationed services for local computational resources that can be discovered and used by other VO nodes. Although standardization endeavors (e.g. for service interaction and discovery) have been carried out individually (especially for Web Services), no universal standard has yet been established allowing for the mediation among the four architectures.

This paper claims that existing approaches for distributed computing should not be regarded as isolated applications, but rather as single integral parts of a complementary architecture. A complementary or *integrating* architecture can utilize a plethora of different VOs that, in turn, can be deployed for many problem classes in the area of construction informatics. As an essential requirement, an integrating architecture should incorporate a common vocabulary or so-called *ontology* so that even different or incompatible services (e.g. an agent and a Peer service) can communicate exactly with each other without any loss of semantics. Ontologies not only increase the interoperability between services, but also improve retrieval capabilities of services and resources within VOs. Design issues and suitable application scenarios for an integrated architecture are illustrated in section 3.

2 STATE-OF-THE-ART

2.1 *Interoperability: Web Service Architectures*

Web Services are a new kind of web-enabled applications. They are self-contained and self-describing entities that can be published, located, and invoked across the web [Tidwell, 2000]. Web Services support distributed computing and offer the possibility to create modern *service-oriented architectures* (SOA). One of their key aspects is to provide a broader interoperability between providers, applications, and platforms than previous standards like CORBA have achieved. In order to reach this goal, several standard are proposed by the World Wide Web Consortium (W3C) meeting the Web Services Architecture (WSA) [Booth *et al.*, 2003].

Web Services are build on technologies like XML, XML Schema and XML-Namespaces. The basis technologies for communication, definition, and discovery are SOAP, *Web Services Description Language* (WSDL) and *Universal Description, Discovery and Integration* (UDDI) [Curbera *et al.*, 2002]. On top of these specifications Web Services allow the creation of business processes (workflows) through the *Business Process Execution Language for Web Services* (BPEL4WS).

2.2 *Integration of Resources: Grid Architectures*

While Web Services offer a standardized platform for building (technical) interoperable service-oriented software, *Grid architectures* additionally are concerned with coordinated resource sharing and problem solving in dynamic, multi-institutional VOs [Foster *et al.*, 2001]. These VOs encompass individuals and/or institutions involved in *sharing* their (computational) resources. Resources to be shared contain computers, software, data, and storage.

Achieving interoperability of these heterogeneous Grid resources is an essential pre requirement for Grid architectures in order to support VOs. Therefore the Grid community that is, the *Global Grid Forum* (GGF) released the *Open Grid Service Architecture* (OGSA) as well as the *Open Grid Service Infrastructure* (OGSI). These standards specify the interfaces of so-called *Grid Services* as well as lifetime management, notification and other aspects of their Grid resources [Foster *et al.*, 2004].

The specification of Grid Services is based on the established Web Services standards, mainly WSDL. Owing to proprietary enhancements of the WSDL specification, Grid Services were incompatible with general Web Services. The recently proposed *Web Services Resource Framework* (WSRF) re-factors the OGSI taking into consideration new developments of the Web Services Community in order to release a Web Service as well as Grid Service compatible standard [Czajkowski *et al.*, 2004].

2.3 *Autonomous Computing: Agent Architectures*

The benefits of *pro-active and autonomous agents* for handling complicated problem solving and planning assignments have been elaborated extensively in the area of artificial intelligence (see [Russell and Norvig, 1995] for an overview). The relatively novel approach to adopt software agents as an architectural style for distributed systems has resulted from modern programming languages like Java that allowed the straightforward implementation of the key characteristics of agents. In addition, standard protocols like the FIPA convention [FIPA, 2002] have emerged for normalizing, in particular, communication between agents. Agent communication is based on so-called *speech acts* accomplishing an almost "human" interaction between agents. Recent agent platforms (environment in which agents operate) like JADE also allow for the *migration of agents* (including data and code) through several network hosts enabling flexible computations on remote sites.

2.4 *Self-Organization: Peer-to-Peer Architectures*

The Peer-to-Peer architecture style describes a distributed architecture consisting of equal clients or so-called *Peers*. Peers are capable not only of consuming, but also of providing computer resources like data, legacy applications, or even hardware resources. Resources are encapsulated by *Peer services*. Peer Services can be published throughout a given Peer-to-Peer network, whereas the Peers themselves are responsible to manage the publication and the discovery of Peer services. Depending on the structure of the topology, a Peer-to-Peer network can encompass several well-know super Peers for a better maintenance of Peers services. The topology of Peer-to-Peer networks is *dynamic*, which results from the volatileness of the constituting Peers, as these mainly correspond to volatile and potentially unreliable nodes (e.g. PC, notebooks). Existing frameworks and architectures (e.g. JXTA [Sun, 2005] or DeEvolve [Alda and Cremers, 2004]) enable single Peers to organize into so-called *Peer groups*. These self-governed *virtual* communities can share, collaborate, and communicate in their own web without a central authority. The purpose is to subdivide Peers into groups according to common interests, competencies, or knowledge independent from given organizational or network boundaries.

2.5 *Semantic Issues: Ontologies*

Future developments in the field of service-oriented computing should consider semantic issues. Semantic description is required for annotation of services and their resources to support both semantic discovery and semantic interoperability in VOs and workflows used within VOs. For example, identification of relevant services should be done through semantic descriptions rather than syntactic definitions. Today, neither WSDL nor UDDI support semantic issues. Semantic aspects can be defined by *ontologies*. An ontology is an explicit specification of a conceptualization, while a conceptualization specifies objects, concepts and relationships that hold them in some area of interest [Gruber, 1993]. Technologies for specifying ontologies are well known in the field of Semantic Web applications. Based on the *Resource Description Framework* (RDF) and RDF *Schema* (RDFS) the W3C released the *Web Ontology Language* (OWL) as a standard for Web ontologies. This language is used by several groups in the context of Semantic Web Services. They use OWL for annotation, discovery and interoperability of semantic enriched Web Services [Paolucci *et al.*, 2002] [Radetzki and Cremers, 2004].

3 PROPOSAL OF AN INTEGRATED ARCHITECTURE

3.1 *Design Issues*

The different software paradigms described above claim different aspects within distributed computing and VOs. Additionally ontologies are seldom considered while standardization of technologies for these paradigms. On this account we propose a *Next Generation Semantic Grid* which integrates several software technologies in conjunction with ontologies. Fig. 1 illustrates an integrated view of this proposal. The basis of this architecture is the Web Services technology which provides standards and basic interoperability in service computing. On top of these standards Grid Services allow building VOs w.r.t. resource sharing in VOs. Mobile agents act as autonomous entities within the Grid solving problems without user intervention. Finally the Peer-to-Peer paradigm enables VOs w.r.t. users groups or interests. That means for instance, different Peer groups can be created in different project phases.

Orthogonally we require ontologies on every level of this software architecture in order to express semantic issues. This topic is represented in Fig. 2.

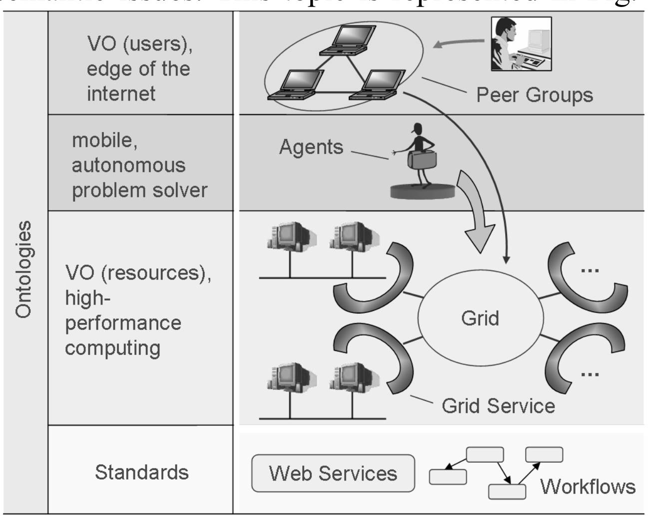

Fig 1. Integrated view of Next Generation Semantic Grid.

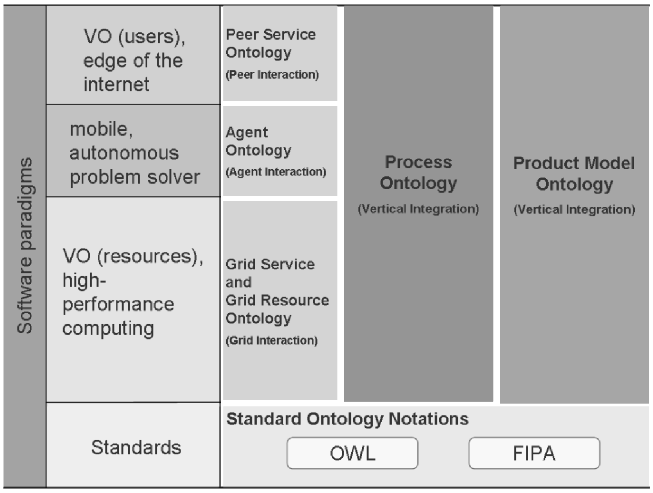

Fig 2. Ontologies w.r.t. integrated software paradigms.

Here OWL and FIPA support basis standard description languages. Moreover, FIPA announce that FIPA agent technology and Semantic Web technologies will be interoperable in future. These languages can be used for annotating and describing services as well as processes (workflows). On every level of the software paradigms we require special ontology-based description languages. These languages contain concepts and relationships which are needed for the specific layer. For instance, on the Grid layer we demand ontology description of the Grid Services and Grid resources. Today, basis ontology description languages are available for Semantic Web Services and Service-Mediators [Martin, 2004] [Radetzki *et al.*, 2004]. Additionally there is the need for a process ontology as well as a product model ontology which are software paradigm layer independent (*vertical integration*). The process ontology describes how the different components fit together in one VO, while the product model ontology defines a common structure for objects and data which are produced and exchanged within a VO.

3.2 *Application Scenarios*

A *Next Generation Semantic Grid* architecture as proposed in section 3.1 has the potential to enhance a plethora of concurrent planning and management activities in construction engineering projects that are carried out in terms of VOs. Foreseeable, future projects in this area will exhibit a broadening demand for collecting, maintaining, and evaluating massive amount of computational data. This data will result not only from the VO's core processes (e.g. partial building or structural design models, and simulation models that are generated within virtual planning organization), but also of accompanying management activities like facility and risk management. The avail of an integrating architecture for supporting facility management is illustrated briefly by the following example.

Facility management as a strategic management activity aims at optimizing the administration and maintenance of buildings within an enterprise [Kolbe *et al.*, 1997]. The key task of an adequate Computer Aided Facility Management (CAFM) system is to gather and to structure (heterogeneous) data that, in turn, serves a Facility Manager as a foundation for further analyses. The majority of current CAFM systems only allow for inputting and examining data manually. Apparently, for future application scenarios, massively distributed and more extensive and more precise data may be gathered from different sites, in order to run highly concise analyses and future predictions about the state of all building of an enterprise. Data may be entered manually by arbitrary end-users (Peers) and also derived automatically by autonomous agents that interact with local sensors (e.g. light, fire, or temperature sensors). The analyses will no longer be conducted and reported by the facility manager alone, but also by analysis routines that run simulations and sensitive analyses with respect to the derived data. Grid VOs are then responsible for providing the massive storage and cycles required for processing the data. On top of the integrated architecture, a common ontology is instrumental to increase the interoperability between potentially heterogeneous data formats.

4 CONCLUSION

Processes and product models for Civil Engineering, object-oriented software technologies, and Internet Information Systems have greatly improved recent contributions of Construction Informatics for the global and dynamic challenges that construction enterprises are facing today. Aspects of efficient cooperation will become more and more important and constitute future topics in this area. The present paper has discussed various aspects that are essential for the evolution of Virtual Organizations. We have shown that Web Service, Grid, Peer-to-Peer, and Agent technologies together with ontologies are complementary technologies for Next Generation Semantic Grids that will meet the demands of future VOs. In fact, the challenge from interdisciplinary applications such as facility management turns out to be a major reason for the integration described here.

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