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Towards the Semantic Grid: A State of the Art Survey of Semantic Web Services and their Applicability to Collaborative Design, Engineering, and Procurement

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ABSTRACT

Today, organizations within the engineering and manufacturing domains place as much emphasis on the management and flow of knowledge through a value chain as they do commodities that are more tangible in nature. For example, parts suppliers in the Canadian automotive sector are often asked to collaborate with auto manufacturers in designing and engineering their product, instead of simply producing and supplying it. Such fundamental changes in the overarching economics of this industry have led to a greater focus on collaboration, both in terms of communicating across geographic divides to design components, as well as new requirements to merge heterogeneous data stores in order to manage this distributed procurement process.

Our work on this project centred on finding solutions to the above by surveying the state of the industry, as well as assessing the potential employability of related tools in the workplace. It was concluded that the Access Grid (a low-cost, open-source videoconferencing platform) held significant potential to facilitate the high-quality sharing of audiovisual material, while semantic technologies (the "semantic web" and "semantic web services") represented a feasible solution to the issues of data integration. When combined, these technologies form the "semantic grid", the focus of this paper. Overall, it is concluded that the past and present business success of this ICT in the information management sector may, with future work, link databases with the visualization interface to provide concurrent cost-benefit analyses.

INTRODUCTION

This paper partially serves as a "business roadmap" for an international joint research initiative of Ryerson University in Toronto, Canada and the Fraunhofer Institute (Fraunhofer IAO) in Stuttgart, Germany. The overall

purpose of the project was to study the impact of emerging and convergent web and broad-based communications technologies on collaborative industrial design and manufacturing. Our primary work focused on creating new tools to better facilitate collaborative design and engineering, and this involved extending the Access Grid (AG) – a robust, open-source videoconferencing platform – to bridge geographic divides in the design process. Our interactions with the tools themselves are more fully detailed in a separate, forthcoming paper that we have authored (see also Fischer & Fraunhofer, 2006; Fischer, Murphy, Tippmann & Ayromlou, 2006, for background information).

Our main focus in this paper concerns how this AG-enabled environment could then be annotated with semantic web services to make connections with existing procurement systems and parts databases. In doing so, it is hoped that the system could make inferences as to how manipulation of the design by any end-user affects the supply chain in terms of procurement and/or manufacturing costs. In this case, we refer to the semantic web services as being "ubiquitous" because of the focus on distributed, collaborative workflows. Our work was primarily focused on the impact to information management within the automotive sector to meet the immediate needs of our industrial partners. However, we do consider other applications (both within and outside of engineering and manufacturing) in this paper where appropriate.

Research Objectives

The objectives for this project were three-fold: first, to explore the potential and predicted impact of emerging technologies on collaborative industrial design; second, to assess the risks, potential return and probable development direction of these technologies so as to allow for strategic adoption by select businesses; third, to outline an actual technical reference architecture that can be implemented to meet specific requirements. This paper endeavours to meet the first two objectives by surveying the state of the industry and analyzing technological achievements with respect to their applicability and viability for deployment in business. As well, we include general descriptions of the progress made in developing actual code to support the above; however, more complete details (and the reference architecture itself) will be summarized in a more technical paper once further testing and analysis is completed. At this time, we are most interested in disseminating our work to professionals and academics in the fields of information and business management across a variety of industrial sectors.

Organization of this Paper

The next section provides the impetus for this project, namely the trends in industrial design and manufacturing that require innovative solutions to changing economic models and advances in IT. We then introduce the concept of the semantic web and semantic web services, detailing their evolution, an analysis of the technology, and highlighting relevant adoption within industry. Then, combinations of the Access Grid and the semantic web (the "semantic grid") are introduced, encompassing the usage of semantic mark-up languages to enhance both conferencing activities as well as supply chain management. Finally, we conclude by outlining future research opportunities that can be undertaken towards creating a "Semantic Services Broker" for our target industries, both within and outside of the lab. A list of references will complete the paper.

INDUSTRIAL PERSPECTIVES

We focus the majority of this paper on the impact to industrial design, engineering and procurement in the automotive industry since there are compelling arguments for adoption that can be made given current and predicted market conditions. It is important to first provide some background in this regard so as to create a framework within which the need for our research can be contextualized. Accordingly, this section serves to briefly introduce trends in how the automotive sector in Canada does business today, as well as what experts predict the future impact new IT may have thereupon.

The Canadian Automotive Sector

In addition to bridging more obvious communication-related gaps present in today's geographically fragmented automotive industry, the resultant shift in the economic model also requires seamless integration of database systems amongst each company's supply chain and/or the creation of an entirely new database consisting of this "merged

data" (which is less desirable since many companies have invested considerable resources in developing the systems they presently use). The quality of data exchange among collaborators is the single most important factor in ensuring seamless integration of supply chains in a heterogeneous and distributed environment. Proof of this can be found in the American automotive sector where lack of standardization amongst companies is estimated to cost the industry more than $5 billion annually (White, O'Connor & Rowe, 2004 as cited in Ameri, 2007). Extrapolating this warning to Canadian counterparts is indeed realistic, given the close trading ties between nations.

Therefore, all organizations who take part in collaborative design must understand how modifications at either end will affect their own supply chain, the chain of every other impacted company, and the overall linkages between them. And if every company involved manages their assets through differing and/or proprietary means (e.g. use of various commercial software packages presently on the market), collaborators cannot uniformly access the data necessary to optimize the design process. New enabling technology is required to bridge this data gap, and this is the primary motive for our work with the semantic web and semantic web services.

Advances in Information Technology

This emphasis on being proactive is also applicable to web technologies that facilitate and enhance this collaboration. While the public sphere is in the midst of a "revolution" from "Web 1.0" technologies to those of Web 2.0 (blogs, wikis, folksonomies and other forms of interactivity and social networks), corporations are awaiting further evolution of the semantic web and semantic web services (which can be considered Web 2.0 for the corporate sphere in some respects). It is predicted that this paradigm shift towards web sites and services that are created using languages more easily understandable to machines (those that are XML-related, such as RDF and OWL) will both reduce costs and improve the quality of content management, system interoperability, and database integration within the next 5 to 10 years (Gartner, Inc., 2006b). This is certainly a favourable outlook that merits further exploration.

Moreover, as Web 2.0 adoption by industry increases in the coming months, it is suggested that the implementation of semantic technologies is particularly apt, since there is strong potential for application and data sharing both internally and externally due to an enlarging user base (Gartner, Inc., 2006a). The need for adoption is justified by the value placed in the quality of data exchange (as discussed; see also Gartner, Inc., 2007c), and to optimize this process, Gartner recommends the transition be accomplished in multiple, small-scale initiatives beginning with semantic hypertext annotations to current web services (2007a; 2007b). In keeping with this recommendation, we proceed to explore the relevant technology in greater detail, as well as the initiatives various researchers and companies have taken to advance the state of the art overall. Here, the focus is on lending further support to Gartner's assertions.

THE SEMANTIC WEB

Technologies such as the semantic web and semantic web services (collectively referred to as semantic technologies in this paper) have the potential to add context and intelligence to web-based applications that can then be utilized over a distributed collaborative network like the Access Grid. Consequently, they are a key enabling group of technologies for our work on this project as it relates to industrial design and engineering. In preparation for a discussion in the next section involving the AG and SWS combined, we continue here with a general, non-technical introduction to semantic technologies. Specifically, we will: discuss the limitations of the current World Wide Web and related web services; introduce the semantic web, comparing and contrasting it with the status quo; relate its evolution to more visible next-generation web services, namely Web 2.0; consider the business case for the semantic web, and provides examples of its adoption; and conceptualize semantic web services and their use in business.

Limitations of the Web at Present

Content that is authored for the World Wide Web (WWW) and related web services today differs significantly from what is proposed within the framework of the semantic web and semantic web services. When the original concept of the WWW was conceived in 1989, inventor Tim Berners-Lee (director of the W3C or "World Wide Web Consortium", a group that develops recommendations for standardizing the development of web sites and services) intended for the overall knowledge representation model to encompass semantics in the form of machine-

understandable data (Berners-Lee, Hendler & Lassila, 2001). Of course, no matter how visually attractive and/or interactive the web experience has become, the end result remains largely understandable only to the human user: a URL that is accessed via HTTP, for example, calls up web content written in a language such as HTML that contains markup designed largely to instruct the web browser how to display the content written by the programmer.

More simply, the markup language or authoring platform (be it CSS, Flash or even Java) codes for how the content should be displayed or how it should interact with the end user, while purporting little (if any) information as to what the content is or what it means within the given context. As such, when a user searches for web content using any leading search engine, he or she is forced to sift through the results manually to select the most appropriate response to their query. For example, a search for "jaguar" returns results for the animal, the car, and the operating system; naturally, a Boolean phrase will reduce erroneous hits, but this is dependent on each individual website's use of appropriate metadata.

While the situation described above is often nothing more than a mere inconvenience to the average end-user in the public sphere, the result can be markedly different in a corporate environment that relies on agents to complete business-to-business transactions (e-commerce) and/or understand the impact of decision-making in-house. To this end, companies can reduce confusion by creating database systems and web services by using a language like XML to code some meaning into the system as a whole.

However, even the most rigid of knowledge/product management systems will remain proprietary unless organizations adopt standardized ways to represent their content through markup languages and taxonomies (data cannot be shared unless all organizations within a sector subscribe to the same principles, terminology, etc.). In summary, there is a need to facilitate both "intelligent" intra and inter-organizational collaboration, and semantic technologies are a proposed solution to this requirement.

In both personal and business situations, it is important to remember that a common limitation of the current web is that it is conducive neither to the understanding of content by machines nor their ability to make inferences and informed decisions based on the data as a result. It is best to think of our experiences with the WWW and web services as pertaining to a vast grouping of documents, understandable only by humans and lacking any real organizational schema.

Attempts to rectify this problem by making data machine-readable are accomplished, in the public/consumer sphere, by tagging and other elements that define "Web 2.0" (to be discussed later), and in the corporate environment by a more rigid taxonomic structure that provides for the annotation of data using semantic markup languages. Describing how the latter can be achieved is what we will discuss next in a more specific introduction to the semantic web as it relates to business applications.

Components of the Semantic Web

Realizing Tim Berners-Lee's original concept of a web of machine-understandable data within a well-defined framework of meaning has been a prime focus of the W3C as of late. The idea was largely revived in 2001 in literature that, while highly speculative, outlines the proposed knowledge representation system in great detail (such documents generally comprise the references for this section). Furthermore, that which was not achieved at the outset of the World Wide Web is thought to indeed be possible today due to advancements in web markup languages (Hendler, Berners-Lee & Miller, 2002). More specifically, the notion of encoding meaning within content is possible by using combinations of XML (Extensible Markup Language), RDF (Resource Description Framework) and OWL (Web Ontology Language), the latter two having received their final approval from the W3C in early 2004 (Miller, 2004). A full exploration of these concepts will prove too technical for a business roadmap; nevertheless, it is useful to consider holistically the role of each technology in contributing to the intended final product.

While all of the abovementioned web technologies support the evolution of the web at present to the semantic web through incremental changes, the W3C's "Semantic Web Activity Group" delineates the role of the components as follows: XML is the foundation for machine-readable descriptions, as it provides for syntax and schemas that can be used to create "vocabulary" to represent the web content; RDF actually adds semantics by outlining the rules by which the XML vocabulary can be described (RDF makes descriptions), while a corollary to this language, RDF Schema, can reduce the XML coding into a single vocabulary (RDF-S combines descriptions); finally, OWL is used

to define ontologies, structures that more clearly outline key terms and their relationships to each other within a specific area of knowledge in a form that is meaningful to computers (Miller, 2004).

As an analogy, we can consider how an auto part like "catalytic converter" would be represented in a semantic fashion: the name of the part itself would be codified in XML, the fact that it is used to reduce the toxicity of emissions is represented using RDF, and the fact that it is part of the exhaust system would be part of the broader ontology (written in OWL) that defines the overall context. Or, put another way, whatever is codified by OWL dictates the vocabulary we have available to describe things and their relationship to each other, while RDF actually provides the semantics for a term in XML.

One of the most significant criticisms regarding the modelling of data in this highly-organized yet rigid way, concerns the amount of time humans must invest in creating the ontology (the "world view" that defines terminology and relationships) before any actual work by machines can take place. Additional software, however, can assist in automating the construction of an ontological model for specific companies and/or industrial sectors, thus saving time.

Most notably, European researchers have refined a tool known as "OntoLearn", which can capture "kindship" relations (e.g. ABS is a kind of braking system) and assigns concept identifiers to each term for more efficient semantic interpretation later (Missikoff, Navigli & Velardi, 2002). In two tourism-related projects undertaken within the study, these researchers noted that about 300 concepts were modelled using OntoLearn over a one-year period and with a precision rate of 84 percent. Therefore, much in the same way that one must laboriously train voice recognition software to improve accuracy, those wishing to utilize semantic technologies will find that the quality of the end-result will correlate positively with the level of detail contained within the ontology involved.

Relation to AI & Consumer Technologies (Web 2.0)

By this point, it may seem like the semantic web (and the web services that will be discussed) represents some form of artificial intelligence, due to the inferencing capability that is possible when data is annotated in a machine-readable form. In certain respects, semantic technologies can indeed be considered a form of "weak AI", but it is argued that scale and scope are the factors that differentiate the two: whereas the intent with AI is generally to allow for automated expressivity to a considerable degree, the semantic web, and its inherent technologies, set out to define highly-specific knowledge areas using as little descriptive information as possible (namely the equality or inequality of particular items coded in RDF, within a broader OWL ontology; Hendler, 2007). This level of semantics is considered adequate for industries engaged in manufacturing, since the goal is to optimize the supply chain and reduce "artificial stupidity" of computer systems at present in order to automate certain laborious knowledge management activities within the enterprise (Mannings, 2007). Therefore, much in the same way the assembly line has automated repetitive physical tasks, the semantic web can reduce the need for human intervention in everyday transactions.

The other major concept which must be contrasted from the semantic web is the Web 2.0 phenomenon. In the consumer sphere, this umbrella term encompasses web content that promotes not only user interactivity, but also the democratization of the web through the end user's ability to "tag" content using their own conventions for the purposes of organization and retrieval. Examples of these web sites and services include certain blogs, wikis, social networking sites, and photo sharing applications. While the annotations that form a part of these applications are useful for more intelligent information management and retrieval, they are far less formal than what is required in the semantic sphere. Therefore, the key difference between Web 2.0 and semantic technologies is that the latter requires a taxonomic structure for classification that is set out in an ontology (use of OWL, RDF, etc. to convey machine-readable meaning), while the former relies on easily modifiable user "folksonomies" to categorize data.

As such, Web 2.0 technologies are inappropriate for most corporate applications because the "wisdom of crowds" philosophy and participatory nature that is inherent within (i.e. depending on peers to continually review and update group conventions, such as with a Wiki) would simply be impractical in business, due to most organizations having clear divisions between the application developers and application users (Greaves, 2007). It is this attention to formality in a more centralized environment that will allow companies to create and use such applications effectively in their daily operations, hence their recommended adoption over Web 2.0 and exclusive consideration in this paper.

Usage of the Semantic Web in Business

Although outside of our target domain, a notable example of a working prototype of a semantic application is "CS AKTive Space", a knowledge management system that lets the user query, explore and organize a catalogue highlighting various research initiatives in the field of computer science in the United Kingdom. Its construction is based on semantic markup languages that, as such, provide inferencing capabilities to the machine (Shadbolt, Gibbins, Glaser, Harris & Schraefel, 2004). While this application obviously has limited usage potential outside of academia, it is important to try and extrapolate the value of proof-of-concept examples like these, since it is advantageous for enterprises to disseminate the results of such studies before investing time and money in implementing the relevant technologies. In this case, success in creating semantically-enhanced databases in a research institution bodes well for adoption in business, since the general purpose and overarching need for a way to organize data in a manner that allows for intelligent querying and sharing, remains the same, even though the actual content contained within the database will obviously differ.

To this end, a variety of major organizations are utilizing semantic web markup languages to create database systems that would allow their internal and external end-users the ability to locate information more efficiently. According to Project10X, a consulting firm, at least 190 companies, including Adobe, AT&T, Google, Hewlett-Packard, Oracle, and Sony, are developing semantic tools in tandem with the prediction that the market for such services will increase from $2.2 billion US at present, to more than $50 billion US by 2010 (Davis, 2006 as cited in King, 2007).

Today, some of the more prominent examples of early adopters in the corporate sphere include the following: Eli Lilly, a drug manufacturer, which wishes to reduce its R&D costs by one-third over the next five years by using semantic ontologies to better categorize its experimental results with different chemical compounds; Citigroup, a financial services organization, who is evaluating semantic technologies that may help its traders and analysts better locate financial data on the web; finally, NASA's Jet Propulsion Laboratory, which is presently testing tools that are designed to help engineers annotate research data for more efficient subsequent retrieval by colleagues (King, 2007). Such examples solidify the assertion that semantic technologies are presently under investigation by a variety of industrial sectors, and that they are indeed emerging as important tools for information management both within the organizations that adopt them, and in terms of how such companies interact with their clients.

Conceptualizing Semantic Web Services

With this basic knowledge of semantic web components, it should be clearer that more is possible in terms of automated data exchange and more "intelligent" web searching, due to the amount of meaning that can be represented in a machine-readable form. This concept can be extended to web services, which ultimately permeate our lives since we turn to them in order to distribute content amongst organizations (e.g. enabling e-commerce transactions), or provide a benefit to the end-user (e.g. a shopping "bot" that can automatically locate a desired product and purchase it on the user's behalf).

At present, web services have a similar weakness to web sites in that their Service Oriented Architecture (SOA) is not annotated semantically: it is built on languages such as UDDI (Universal Description, Discovery and Integration), WSDL (Web Services Description Language) and SOAP (Secure Object Access Protocol), none of which independently allow for automated understanding and processing by machines (Davies, Fensel & Richardson, 2004). A progression to semantic web services is thus essential and it is within this framework that we later discuss a "Semantic Services Broker" that will link semantic web services (SWS) with the Access Grid.

Designing new web services (or re-designing existing ones) to purport machine-readable semantics can be completed within an OWL-based ontology framework, but requires a markup language with more expressive power than RDF/RDF-S and XML combined; for this, the usage of a new family of coding technology, DAML (DARPA Agent Markup Language) is recommended (McIlraith, Cao Son & Zeng, 2001). Researchers have further suggested a more all-encompassing conceptual model for this representation, the Web Services Modelling Framework (WSMF) and its compliment to OWL, the Web Services Modelling Ontology (WSMO) directive; both being designed to improve business-to-business interaction, especially e-commerce transactions (Davies et al., 2004).

In one case study that demonstrates the ability of SWS architecture to overcome integration problems inherent in the e-commerce process (regarding the exchange of data amongst participating companies), Richardson and Midwinter (2006) utilize semantic web services to: a) represent the contract catalogue of a computer manufacturer as an ontology, b) design an ordering system using the abovementioned languages, and c) enable the sharing of heterogeneous datasets between the company itself and its constituent suppliers within its value chain. Additionally, companies are embracing semantic web services in a desire to improve the overall user experience: most notably, in April 2007, ZoomInfo launched what it claims to be the first market-ready search engine for business contact information that relies on SWS technologies to mine and assemble data without human intervention (King, 2007).

Overall, while companies wishing to institute SWS will need to overcome the same overhead inherent across all semantic technologies (namely the resources required to create and maintain ontologies), this fusion of the semantic web with existing web services architecture does show potential for achieving the level of standardization desired across companies involved in business-to-business transactions. In fact, it is predicted that innovation in this regard will lead to a more efficient supply chain and economy because information can be exchanged more quickly and automatically with a high level of accuracy – this view is at the root of the field of "semantic e-business", which encompasses traditional e-business and knowledge management at their intersections with the semantic web and semantic web services (Rudall & Mann, 2006). Examples of this forecast, and a greater exploration of this new discipline as it relates to engineering, are the focus of the next section.

THE SEMANTIC GRID

While state of the art surveys for constituent technologies are important in establishing a case for their respective adoption within business, so too is considering attempts to combine them for use within the domain of collaborative industrial design and procurement. As such, we devote this section to the notion of the "semantic grid" and its potential to transform how our target enterprises do business. Specifically, we will survey: what the "semantic grid" is and what it encompasses; how convergence between the technologies is predicted to transform business models; applications that may enable distributed and collaborative industrial design and engineering; applications to manufacturing and supply chain management (SCM); and requisite areas for improvement to address concerns of security and privacy.

Introducing the "Semantic Grid"

The term "semantic grid" can refer to any attempt to apply semantic web technologies to a grid computing environment, in our case the distributed resources that are interconnected via the Access Grid. In a recent paper outlining a research agenda for this technology, De Roure, Jennings and Shadbolt (2005) note that combining these two concepts is logical, as they share a common goal of bridging heterogeneity amongst computing resources, information, knowledge, time, and space. They also note that the most important goals of the project are to enable resource description, discovery and use, as well as support context-aware decision-making across communities dubbed "smart environments" (so named because of the ambient intelligence for which they can provide).

The directions set by this team evolved largely from the UK's "e-Science Program", a consortia of various academic institutions and more than 80 companies focused on researching middleware requirements for intelligent distributed collaboration in both science and e-business (both have similar issues that must be overcome in this regard; De Roure et al., 2005). Overall, the notion of the "semantic grid" seeks to exemplify the interdependence between the key constituent technologies while facilitating a more collaborative workforce.

The "semantic grid" generally serves as a means to an end in terms of improving the design and procurement process both within and outside of the automotive industry. However, we can also consider how the semantic web component makes use of the Access Grid itself more efficient (which, in turn, only stands to improve the use of the combined technologies). Specifically, some attention has been devoted to using semantic annotation to enhance the process of real-time collaboration enabled by the AG: Ben Juby (2006), for example, outlines processes by which speaker identification and participant tracking can be added to the Access Grid using RDF; he also highlights the University of Southampton's "CoAKTinG Project" (Collaborative Advanced Knowledge Technologies in the Grid) as a further example of distributed collaborative semantic annotation enabling features like graphical concept

mapping and the ability to record, automatically catalogue, search, and replay parts of meetings held over the AG. We too will continue with our own efforts to integrate SWS with the AG to make use of the latter more efficient, as well as assisting our target industries go about their business. However, we focus the remainder of this section on assessing the "semantic grid's" overall ability to influence business models within the engineering domain as a whole.

Transforming Business Models

The concept of the semantic web and SWS transforming business in more general ways, such as through greater efficiency in e-commerce transactions, were discussed in the previous section. This notion of "semantic e-business", however, has particular resonance in both collaborative industrial design/engineering, as well as the manufacturing supply chain. With respect to the latter, the physical supply of product moves down the chain from suppliers to end-users, while details regarding demand moves upstream. Therefore, coordination of actual transactions with the database systems that enumerate them is essential. According to Levary and Mathieu (2004), the "semantic grid" has significant potential to improve such information flow, since the process of sourcing goods and services, and reporting transactions that have taken place, can be automated to a certain extent. In doing so, the need for human intervention is thus reduced.

Overall, the end result here is that new technology would allow computing systems to act as agents that could find vendors who are able to meet supply requirements within given specifications and timeframes. As a corollary, this is consistent with the broader goal of semantic and collaborative work technologies to effectively narrow the gap between business directives and the information technology used to achieve them (as outlined in Lee, 2005). Here, the existing model of any industry value chain (such as the auto and auto parts sectors) may be transformed, since the objective (in this case, managing the supply chain efficiently) has converged with the information technology used to accomplish it.

In other words, a company in this case would direct considerably more focus to developing software/web service applications to actually carry out SCM-related tasks and linking them back to those involved in the industrial design phase, rather than designing the software/web services primarily for human interpretation and use. As mentioned, however, the human factor is not entirely removed; rather it is re-purposed to the area of knowledge management and organizational expertise. Obviously this is only one example of model-driven business transformation caused by the "semantic grid", but it greatly impacts the way design, engineering, and procurement activities are carried out.

Given how little time such models of semantic e-business have been considered and adopted, it is difficult to provide any definitive assessments as to whether or not such a concept has met the predicted impact (examples in academia and some businesses demonstrate a certain level of willingness for greater deployment, but they do not necessarily offer thorough, long-term forecasts). As such, it may be useful to consider how distributed and collaborative semantic technologies, and their ontological framework in particular, have evolved with respect to business models. Henry Kim (2002) posits that the ontology, arguably the basis for the semantic web, SWS and the "semantic grid", will have an effect on industry that is analogous to the way in which standard operating procedures and forms transformed daily business operations. To that end, we can conclude that as long as new ontology-based business models reduce uncertainty and make work more efficient for employees in general, they have the potential to be useful.

Applications to Industrial Design & Engineering

With background on each respective technology presented, as well as the previous discussion of the combined "semantic grid" environment, we continue by surveying examples of implementation of such technology in our target sectors and industries. Several research teams have developed prototypes based on semantic and AG-related technologies that were tested as proof-of-concept items within the automotive sector. One of the most notable examples is a web-based repository, the "INTEREST Information Model" or IIM, which is built with OWL and RDF and is designed to enable virtual prototyping and the sharing of designs and component information with all those involved in the broader development process (Brown, Leal, McMahon, Crossland & Devlukia, 2004). According to the authors, this and related projects work by linking CAD design systems with product/SCM databases to form the repository of information that can then be disseminated via an appropriate web service. The

benefits of such a system can largely be found in the improved productivity that comes with having necessary knowledge more readily available, and this was verified in trials involving collaborative fatigue testing of the designs of certain auto parts (Brown et al., 2004).

In a similar development, Axel Hahn (2005) of the University of Oldenburg in Germany has created a wrapper/web service application that, in a similar fashion to the AG, provides the user with access to a shared whiteboard space; however, what sets it apart is a distributed semantic network that, in turn, links product models within various engineering software tools. This project goes beyond both integrated approaches (where only a common knowledge-representation model is used, as in proprietary software) and unified ones (in which processes are mapped to a common model), and instead purports a federated existence, wherein individual models are coupled using a shared ontology (Hahn, 2005). Naturally, this is advantageous to an organization, since individual computing systems and web services can be maintained, so long as a shared ontology can be developed to link things together (recall that software like "OntoLearn" can be used to create this framework in an expeditious and accurate manner).

Another example of such a federated system can be found in an Australian project named "FUSION" (Fuel Cell Understanding through Semantic Inferencing, Ontologies and Nanotechnology), in which microstructural, performance, and manufacturing data and imagery acquired during research on hydrogen fuel cells is catalogued and managed using SWS (Hunter, Drennan & Little, 2004). With this project, specific software ("Vannotea") is used to annotate the data and imagery with semantic markup languages, and collaborative efforts in this regard are enabled through the use of the Access Grid. Since this most resembles our proposed work, we regard it with particular attention going forward.

Finally, it is important to note that the examples discussed above are indeed industry-viable since they comply with an ISO standard known as "STEP" – the Standard for the Exchange of Product Model Data.

This particular standard, in turn, is associated with the concept of "Product Life Cycle Support" or PLCS (ISO 10303-239), a method that allows an organization to manage its engineering assets over their respective lifetimes. Price and Bodington (2004) write at length of the potential for OWL to improve the PLCS standard, first by building a knowledge base of the history of an asset in order to manage it more effectively, and secondly, by using it to coordinate such a history with parts and scheduling databases that can then be distributed as a web service (e.g. determining when an asset will require service, ordering the appropriate parts, and scheduling the necessary labour).

Overall, a study by the National Research Council of Canada (NRC) found that organizations using PLCS/STEP-compliant systems to distribute and exchange data on collaborative projects have reduced development times by as much as 40 per cent, while realizing cost savings as high as 30 per cent (NRC, 2002 as cited in Price & Bodington, 2004). As a result, the benefits of implementing such technologies within any industrial design and engineering-focused workplace should be self-evident.

Applications to Manufacturing, Construction & SCM

Semantic and "semantic grid" technology can also be applied to assist in the realization of a designed component, especially the manufacturing or construction process, as well as the actions necessary to manage the supply chain of both raw materials and the finished product. Much in the same way ontologies can be created to manage the processes of engineering and PLCS, frameworks that incorporate product information, as well as manufacturing techniques and tools, are advantageous towards more efficiently managing a distributed manufacturing process and linking it with the supply chain (Yang, Zhang, Gay, Zhuang & Lee, 2005). Researchers have created several prototype ontologies to this end, the most notable of which include the "Manufacturing System Engineering" (MSE) model (Lin & Harding, 2007), as well as the concept of "intelligent distributed manufacturing" (Kulvatunyou, Cho & Son, 2005). In both of these examples, a virtual representation of the enterprise is created – with RDF and OWL in the case of the former and through the use of DAML in the latter – to facilitate semantic interoperability.

Another area that is worth exploring is the impact of the "semantic grid" on more large-scale manufacturing efforts, namely the architecture and construction industries. Projects in this sector are still heavily dependent on collaboration, though this ordinarily involves contractors co-ordinating their on-site efforts, rather than the management of a value chain/assembly line. Nevertheless, to assist with this, a virtual organization can be created,

in which the activities of all companies involved can be represented, merged, and shared over a distributed environment through semantic web services.

One such application that accomplishes the above is the "Product Supplier Catalogue Database" (PSCD) from ActivePlan Solutions Ltd., which incorporates data (product information, scheduling, etc.) from the clients, designers, contractors, suppliers, and individual product manufacturers, thus enabling them to work collaboratively in a virtual environment to manage a particular project (Miles et al., 2007). This particular program also utilizes the Access Grid and its constituent suite of tools to facilitate the virtual meetings that are equally essential to success in this industry. In a similar development, the Dutch construction industry has benefited from the development of a 3D modelling application (annotated with elements similar to RDF) that provides instant feedback as to whether or not the proposed design meets municipal building codes and aesthetic requirements (van Leeuwen & van der Zee, 2005).

Finally, it is also important to consider the management of the supply chain in greater detail, since we have primarily been focused on how it is connected to other sectors. Supply chain management in itself is a complex field that involves not only business-to-business (B2B) transactions between vendors, but also with the general public through e-commerce. As mentioned in a previous section, it is people who are the agents in most phases of the procurement process at present. And even with adherence to industry standards, there is concern that, as supply chains become increasingly more complex, automatic integration will be required between the systems involved in the process to ensure it flows smoothly.

One approach that may achieve this is the idea of "self-integration", in which the various software applications used in SCM are integrated to complete the tasks of vendor selection and collaborative product development (Jones, Ivezic & Gruninger, 2001). At the time of publication, the authors of this proposed framework envisioned that it could be constructed using semantic web services (the DAML-OIL language in particular), and that it would be relevant to major manufacturers in the automotive and aerospace sectors.

However, the research directions in this field have shifted since the time the abovementioned framework was proposed. Now, the focus is on creating new ontologies to represent the supply chain and bridge heterogeneity between businesses, rather than trying to integrate the existing software. To this end, two new proof-of-concept examples have been developed to take advantage of improvements to the semantic web and SWS: firstly, the "WSCPC" system (Web Services for Collaborative Product Commerce) acts as a semantic "brokering" system that allows one company to automatically respond to the changing needs of its collaborators based on market conditions (Kim, Chung, Qureshi & Choi, 2006); secondly, the "B2BOOM" system minimizes human intervention by using SOAP and TCP/IP to represent and share information (Kajan & Stoimenov, 2005).

The authors of the latter system predict that, as these agents become marketable web services, businesses will be able to focus more on the "bottom line" rather than the inefficiencies of B2B at present. That said, it is worth repeating that notions of "semantic e-business" are relatively new and unexplored in actual SCM environments; therefore, it is difficult to gauge their actual efficacy towards enabling distributed collaboration, though we suspect this will be a main research focus in the coming years.

OPPORTUNITIES FOR FURTHER RESEARCH

One area that academics and industry professionals have not paid considerable attention to is the requirement to secure collaborative systems designed with semantic and AG-related technologies. According to Bhavani Thuraisingham (2005), all layers of the semantic web and SWS are vulnerable to some degree at present. As such, he asserts that a research agenda focused on securing the field of "semantic e-business" through access rules and encryption must be outlined in the near future, so as to protect intellectual property and confidential vendor data.

In this vein, Thuraisingham also draws attention to privacy concerns, since a key feature of semantic technologies is their greater inferencing capabilities that may lead to automation of the decision-making process. E-business in itself is vulnerable by its own nature (sensitive information, financial risk, etc.), but this is exacerbated by the ability of the added semantic annotation to effectively mine data; as such, we recommend that any company thinking of developing and/or deploying semantically-enhanced applications consult with an attorney familiar with privacy

legislation in their particular jurisdiction for advice before proceeding. To this end, further research on the social and political implications of new web technologies is in order and thus warrants additional consideration.

Another chief concern that may hinder any realistic expectations of these technologies being adopted rests with anti-trust concerns among competitors within any industrial sector. Our profile of the auto industry revealed measurable competition amongst the major players, with both profits and human resources at stake. Therefore, we are unsure at present whether or not various companies within a supply chain will want to share their high-risk data in order to facilitate a broader ontology for their particular business. We hope, however, that the benefits of organizations partnering to improve productivity will, in the long term, outweigh the potential risks of doing so. Again, further research from the business management perspective is needed.

CONCLUSIONS

This paper has presented state-of-the-art surveys of semantically-enhanced distributed collaborative visualization environments, as well as the technologies upon which they are based. More specifically, we explored semantic technologies (the semantic web and semantic web services) by discussing their past, present, and predicted use within business. We restricted our survey primarily to the realm of industrial design, engineering, and procurement, while focusing as much as possible on relevance to the automotive sector. Finally, we compared this research with the greater aims the “semantic grid” concept, and suggested areas we feel are worthy of future exploration. Throughout this paper, we attempted to relate our key points using non-technical language, so as to make this document more accessible to its readers. We encourage those seeking more technical details to consult our references; as well, those looking for a more detailed analysis of the Access Grid videoconferencing technology that served as the initial basis for this project would be wise to consult the AG Community’s website at www.accessgrid.org.

We consider the major conclusions from this research to be two-fold: first, significant change is occurring in economic sectors that are heavily dependent on industrial design and the close management of supply chains – new methods of conducting business in the automotive industry are, for example, resulting in the increased geographical distribution of resources, coupled with increased heterogeneity amongst organizations in the value chain; and secondly, we recognize that technology is evolving to meet such needs – for example, the added context provided by semantic annotations are assisting a variety of organizations in collaborating on projects at all stages in their respective life cycle. Ultimately, the onus remains with each company to ascertain what sort of change is occurring within their organization, and to decide whether or not the concepts presented in this paper have the potential to help allay such change.

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