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A semantic service-oriented architecture for distributed model management systems

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ABSTRACT

Decision models are organizational resources that need to be managed to facilitate sharing and reuse. In today's networked economy, the ubiquity of the Internet and distributed computing environments further amplifies the need and the potential for distributed model management system (DMMS) that manages decision models throughout the modeling lifecycle and throughout the extended enterprise.

This paper presents a service-oriented architecture for DMMS. The proposed architecture leverages service-oriented design principles and recent developments in semantic web services to enable model sharing and reuse in a distributed setting. The paper describes a prototype implementation, case study scenarios, and a discussion highlighting lessons learned and implications for research and practice.

1. Introduction

Organizations are increasingly dependent on decision support systems (DSS) and associated models for data analysis and decision support rendering such applications ubiquitous. Supporting the proliferation of such applications is a plethora of modeling languages and platforms, database management technologies, and software engineering approaches for designing and implementing decision support systems. Moreover, with the advent of the Web and distributed computing environments, there is an increasing demand to leverage the existing investment in decision models and data within and across organizations. In this paper, we follow Krishnan and Chari's notion of a 'model' [40]: "*A model (or a model schema) is a formal abstract representation of reality and constitutes an important component of decision support systems. Models can be instantiated with data to create model instances that represent specific problem situations. Model instances are solved by computer executable programs known as solvers to obtain model solutions.*"

Analogous to database management systems, model management systems aim at recognizing models as a corporate (and national) resource that needs to be managed. The objective is to provide the necessary functionalities for manipulating decision models and supporting the modeling process [14,40]. The advent of the Internet created unique opportunities for extending model management functionality such as sharing and reuse in a distributed setting within and across organizations. However, in contrast to data, effort for sharing and reusing models has been hampered by the use of a variety of modeling languages and environments, model formats, difficulty in publishing and discovering models in a distributed setting, and difficulty of executing models in a variety of formats and in a distributed setting.

Service-oriented architecture (SOA) coupled with semantic web technologies can potentially address many of the aforementioned issues. Demirkan et al. [16], emphasize the value that service-oriented technologies and management can bring for businesses. In general, services are independent building blocks that collaborate to deliver application functionality. Services differ from 'traditional' components with respect to the underlying design principles, most notably are autonomy from other services, and compliance to a standard communications framework. The focus is on exposing application logic as loosely coupled services. Design principles underlying SOA emphasize reuse, abstraction, loose coupling, statelessness, composability, and discoverability [20,46]. Semantic web technologies address semantic inter-operability issues thereby facilitating information exchange functions such as model publication, discovery and use.

The objective of this paper is to address problems encountered in sharing and reusing models in a distributed setting. This is accomplished through the design and implementation of a semantic SOA for distributed model management. The rest of the paper follows Peffers et al. [47] and is organized as follows: Section 2 defines the problem and the importance of the solution. Building on the prior section, Section 3 defines the objectives and requirements for the proposed approach. Section 4 describes the design and development of a distributed model management system (DMMS), followed by a demonstration of the functionality of the proposed system and an evaluation of the proposed system in Sections 5 and 6, respectively. Section 7 concludes the paper.

2. Problem identification and motivation

The problem under consideration pertains to issues and challenges encountered when sharing and reusing models in a distributed

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setting. The grand challenge is developing next generation model management systems that are particularly suited to today's distributed environment. The underlying issues and challenges stem from the heterogeneity of model representation formats and the heterogeneity of modeling environments resulting in accessibility and compatibility issues, the lack of awareness of the existence of relevant models, and the lack of universally accepted semantics.

Addressing these aforementioned issues will allow for the seamless exchange of models within and across organizations, for the reuse of models, i.e., using the same model schema with different data sets, different solvers, and different modeling environments, and for the creation of model repositories that can serve as a lasting archive of models. These archives will capture the state of knowledge and will also ensure the availability of these models regardless of the availability of the modeling environment. The utility of a distributed model management system that can address these challenges extends beyond business organizations and is equally important at a national level where significant expenditure is directed to the creation of cyberinfrastructures for supporting research [2]. In this context, DMMS provides the information management capabilities of sharing, reusing, and archiving scientific models for the advancement of scientific research. The following subsections describe a set of motivational scenarios highlighting the challenges encountered in a distributed setting, discuss the current state of distributed model management systems, and describe the contribution of the proposed solution relevant to the current state of the art.

2.1. Motivational scenarios

2.1.1. Scenario 1: intra-organizational model sharing

Consider an organization where there is a need to share decision models among units or branches within the organization. For example, the headquarters uses a decision model for developing the best marketing mix including advertising expenditure, product quality index, and product distribution. A regional branch operating in markets characterized by high variability in demand, different competition conditions, and distribution channels would need to reuse the former model taking into account new parameters and competitive dynamics for its market. Alternatively, various branches may have developed their own models or have adapted existing models to meet their specific requirements. It would be advantageous if each branch is able to share its models with other branches in a seamless manner.

Nevertheless, such goal is often hampered by lack of awareness of the existence of such models in the first place, heterogeneity of modeling environments resulting in accessibility and compatibility issues, and inadequate (or lack of) documentation that often employs inconsistent semantics complicating the problem of assessing the applicability of a particular model as well as the possibility of customizing such models to the situation at hand. The aforementioned issues are even more prevalent in an inter-organizational setting.

2.1.2. Scenario 2: models as knowledge objects

Knowledge intensive business services (KIBS) are private organizations that rely heavily on professional knowledge for supplying intermediate products or services that are knowledge-based [43]. Examples of KIBS include IT support services, management consultancy, and engineering consultancy. According to Hertog [34], KIBS capture scientific and technological information that is often dispersed across the economy, and tailor such information to meet the needs of its client. Interaction between KIBS and their clients involve extensive knowledge flows that take a variety of forms. While tacit knowledge is a significant component of knowledge flow, explicit forms of knowledge such as written reports, project plans, software, and decision models are also prevalent.

For example, consider a consultancy firm that provides services to help its client firms address issues pertaining to their projected energy demand, cost, and optimal mix of their energy portfolio. The firm relies on a number of decision models for forecasting energy demand and supply, prices for various forms of energy, transportation and distribution costs, etc. A client is interested in utilizing energy price forecasting models developed by the consultancy firm that meets its particular needs and is compatible with its own production and distribution models. Given the likelihood that the client may be using different modeling environments and assumptions, such utilization may be severely hampered. The situation is further complicated if the client wishes to select and test a variety of such models for their suitability to their particular needs. Such a situation may be encountered with other clients as well.

2.1.3. Scenario 3: domain specific model sharing — environmental management

While the concept environmental management is not necessarily new, the emphasis on sustainable development has been gaining significant momentum since the Brundland Report [53]. Nevertheless, environmental management is a complex endeavor and provides a rich application domain for decision support systems. Specifically, environmental DSS is often used to handle ill-structured problems, where the structure of the problem and its associated solutions are developed progressively over time using a variety of data sources, analysis models, and visualization techniques. Implementation of such systems must be able to assemble various decision support components to meet the requirements of the problems at hand while catering for the complexity of such tools [1]. With respect to analysis models, a land zoning model may be augmented with a hydrological model to be able to handle water quality issues related to land zoning decisions, a tidal flow model may be connected with a surface flow model as in the HYDRA DSS, simulation models for smog analysis (DYMOS) may be linked to a traffic flow (DYNEMO) to assist with environmental planning, and a geographical information system module may be coupled with a transport model for depicting transport phenomena. Moreover, in environmental management the situation is further compounded by the variety, heterogeneity and multiplicity of analysis models and tools [30]. Such models are often developed independently with different data requirements (both from semantic and syntactic perspectives).

2.2. Distributed model management

Model management (MM) research has attempted to address some of the aforementioned problems. The focus is on providing the necessary functionalities for manipulating quantitative decision models including model representation, model manipulation, model selection, model composition, solution computation, and result information display and analysis [14]. Some of the functionalities of MM resemble those of database management systems (DBMS) such as model description, manipulation, and control [17]. One important function of MM is model selection. Model selection [4] focuses on identifying a model type or schema for a specific problem instance under consideration. With the quest for supporting more sophisticated modeling tasks, research in MM has looked at complex research problems such as model composition and model integration. While model integration deals with orchestrating more complex models from two or more existing models at the structural or definitional level [5,27], model composition deals with sequencing models from the models library at the functional level [15]. A comprehensive review of these functionalities can be found in [11,14,40].

The advent of the Internet, the World Wide Web and the proliferation of computer networks have energized the decision support research community to explore means for sharing and reusing models and decision support tools in such environments. In that regard, Bhargava et al. [7] proposed a web-based architecture for sharing decision models, prototyped as DecisionNet application. The main idea is