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Spatial Decision Support Systems Using Intelligent Agents and GIS Web Services

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Abstract

Spatial Decision Support Systems (SDSS) assist decision makers in analyzing spatial problems and evaluate alternative solutions using applicable spatial and non-spatial data as well as analytical models. SDSS environments are typically built on top of Geographical Information Systems (GIS), which are capable of storing, manipulating and displaying geographically referenced information. Traditional GIS and consequently the SDSS tend to be monolithic with proprietary software, development tools, object models, database access and user interface tools. Hence, many organizations cannot afford this technology and users have a great deal of difficulty using these systems. This paper investigates the use of intelligent agents to minimize the cognitive load on SDSS users as well as explore the possibility of developing distributed SDSS environments using GIS Web Services.

Keywords: Spatial decision support system, GIS, intelligent agent, Web services

Introduction

With the advent of Internet, web-based computing is becoming popular and Web Services provide the mechanisms needed to perform computing tasks over the web without completely developing the application or buying the software. A web service is a software component that can be accessed over the Internet for use in other applications. GIS Web Services provide commercially hosted spatial data and GIS functionality via the Internet to Web applications and users. In a nutshell, GIS Web Services provide GIS content and functionalities to applications without having to invest in costly GIS software and platforms. The clients don't have to host the GIS data or develop sophisticated tools to incorporate GIS capabilities within their applications. This facilitates even smaller organizations with limited resources to take advantage of GIS capabilities without having to incur development cost and time.

Spatial Decision Support Systems (SDSS) are designed to help decision makers solve complex problems such as site selection, routing etc. which have a strong spatial component. SDSS incorporates GIS functionalities such as spatial data management, cartographic display, etc., along with analytical modeling capabilities, flexible user interface, complex spatial data structures, to name a few. Utilizing the Internet as a platform for an SDSS has several advantages (Pandey et al., 2000; Meyer et al., 2003). Web technologies, for the most part, are platform independent—they can be developed once and be used everywhere. Additionally, end-users are, for the most part, already knowledgeable about navigating websites and using web-based tools. Therefore, the learning curve for a web-based SDSS is minimal (Al-Sabhan, 2000). Finally, distributing software and performing updates via the web is much simpler than with traditional software tools. Nothing more is required of the end-user except visiting the updated web page.

Another enabling technology, namely, intelligent agents is gaining ground and early results indicate that intelligent agent technology has the potential to change the way we think about computing. Researchers are focusing on designing autonomous intelligent agents that can support and augment human agents in their day-to-day work and decision making. One could envision a computing environment where the human agent can delegate routine/mundane tasks to these intelligent agents so that he/she can focus on more creative tasks.

Research is underway to investigate the use of intelligent agents in GIS applications and decision making. The focus of this paper is to explore how intelligent agent technology and GIS Web Services can be used in developing a distributed spatial decision support application and provide better interface to GIS systems. Such systems would assist users in utilizing GIS functionalities in their day-to-day work. We contend that with the help of intelligent agents, one could easily find appropriate GIS Web Services on the Web and potentially assemble an application that utilizes GIS functionalities effectively in order to execute geo-spatial tasks.

Background

Intelligent Agents and SDSS

Several research efforts have been reported that use agent technology in addressing spatial decision making problems (Manson, 2000; Sugumaran et al., 2001; Sengupta et al., 2003). Ferrand (1996) reports on a system that is used to solve complex spatial optimization problem encountered in the search for least environmental impact area. Papadias and Egenhofer (1995) report on using agents in Qualitative Collaborative Planning. Agents represent topological, direction and distance constraints that are applied to a spatial planning problem. The focus of this work is on using spatial access methods that can effectively process qualitative constraints represented by agents. Rodrigues et al. (1997) describe a multi-agent based system called MA-MEGGOT, used for modeling geographic elements for environmental analysis in land use management. The system is aimed at establishing methodologies for evaluation and standard simulation in environmental quality description scenarios.

The agents used in the above mentioned projects have a narrow focus and are application specific. Moreover, they are not distributed and hence do not have a well defined inter agent communication, collaboration and coordination mechanism. In our work, we propose a more comprehensive, generic agent-based SDSS where several types of intelligent agents coexist in a distributed environment, and collaborate with one another in solving a particular problem.

As demonstrated by these projects, there is great interest in applying agent technology to GIS environment. We are seeing only the beginning of this cross fertilization between Intelligent Agent technology and GIS technology, and lot more research is yet to be conducted. The agent technology seems to be a natural fit for making GISs user friendly and applicable in a variety of problem solving/decision making scenarios, other than their limited use in facilities management.

Web Services

The Web has become a viable computing environment that facilitates much more than simple sharing of different types of data such as text, images, video, etc. Increasingly, traditional client server applications are being transformed into web-based applications (Zhang and Wang, 2001). Taking it a step further, third party solutions are now beginning to be offered over the web to satisfy user's needs for more dynamic services. This has resulted in new computing environments known as Web Services.

One of the primary goals of Web Service technology is the development of standard protocols that would allow a heterogeneous set of components to interoperate. These protocols are used for interface definition, method invocation, component repository and implementation of the overall application. These protocols also improve compatibility between components. The principles of component based development are expanded over the Internet. In this environment, developers can share their own components with other departments, companies or other developers on the web and develop new applications without the limitation of the underlying component model, language and the distributed object model.

In the Web Services Model proposed by W3C, to provide services, the interface of the service should be described with a standard language. The contents of services should be registered with a registry, shared on the Web. A service repository is a distributed directory of services and has functions for searching and registering. In the service registry, information about service's location and usage are included. A particular user could use one or more of the services at run time to accomplish a particular task. The following standards are used to perform the integration function: a) SOAP – remote procedure call (Box et al. 2000), b) WSDL – interface definition language of web service (Christensen et al. 2000), and c) UDDI – registry of web services (UDDI Project 2001).

GIS Web Services will revolutionize how companies use and interact with geo-spatial information (Gonzales, 2003). With the existence of GIS Web Services, companies no longer have to address the technical side of GIS to exploit its value. User communities can gain extensive analytic value of GIS without the potential problems. This facilitates even smaller companies to render maps and solve routing and logistical problems using spatial analysis without ever having to physically store and maintain spatial database.

The following section describes the architecture of the proposed agent based SDSS environment that makes use of GIS Web Services, and assist the user in executing spatial related tasks.

Architecture of Distributed SDSS

Successful development of any SDSS requires five key components: (1) a Data Base Management System (DBMS); (2) a Model Management System (MMS), including analysis procedures; (3) a display generator; (4) a report generator and (5) user interface (Mennecke, 1997). Along similar lines, the proposed agent-based Web Services SDSS comprises of the following components: a) data management, b) model management, c) knowledge management, d) dialog management, e) intelligent agents, and f) GIS Web Services. The architecture of the SDSS is shown in Figure 1, where the different components may be linked together through Internet or a corporate Intranet. With the advances in Internet/Intranet technologies and Web Services Standards, we envision this distributed SDSS environment being implemented using a secure intranet, without having to install a proprietary network. The components of the proposed SDSS are briefly described in the following paragraphs.

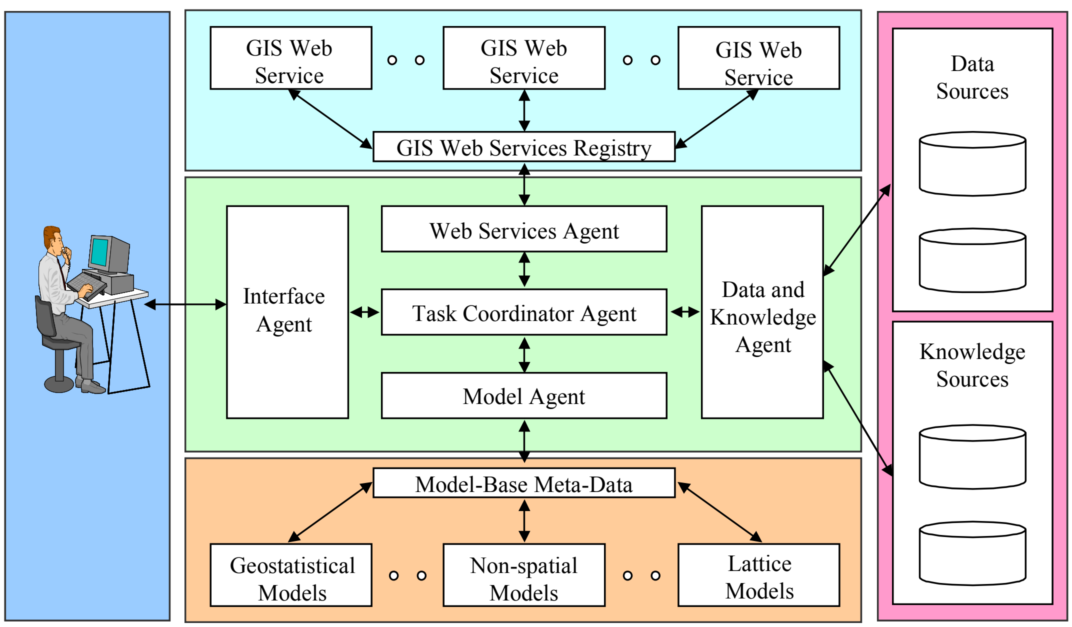

Figure 1. Architecture of Distributed Spatial Decision Support System Using Web Services and Intelligent Agents

Data Management Component

The DBMS component provides data support for the operation of MMS. Data management component provides access to attribute and spatial data. It encompasses traditional databases as well as GIS databases. Thus, the data management component provides easy access to large volumes as well as different types of data. It also provides mechanisms to derive new data sets from existing spatial data based on various criteria and the problem at hand.

Model Management Component

The model management component provides access to a large number of models necessary for analyzing and solving unstructured problems. The model base supports both aspatial and spatial models. It also facilitates development and testing of new algorithms and models. For example, in the domain of environment planning, Multi-Criteria Evaluation (MCE) technique is frequently used, which allows evaluating several criteria in a decision process. This requires a diverse source of information as well as generating multiple versions of the model with varying weighted linear combinations of attributes.

Knowledge Management Component

Corporate knowledge bases consist of a number of information repositories that contain organizational policies, procedures, business rules, and constraints. They also include "domain model repositories" that store information about various application domains, which is useful in problem understanding and analysis.

Dialog Management Component

The dialog management component provides a graphical interface for the user to interact with the SDSS during a session. The interface can be customized according to the tastes and preferences of individual users. It supports different presentation modes as well as reporting capabilities.

GIS Web Services Component

The GIS web services module supports basic geo-processing tasks such as address matching, map image display, routing etc. Applications or agents can use these GIS web services to perform real-time processing on the computers hosting the web services and return the results to the local application. This module uses SOAP infrastructure for communication with clients. The GIS web services are published on the UDDI registry and agents can search this registry to discover appropriate services through SOAP calls.

Intelligent Agent Component

The proposed SDSS consists of a federation of intelligent agents that cooperatively work together in supporting the problem solving activity of the user. They help the user in modeling, analyzing, and solving the specific problem at hand. They take care of mundane activities such as accessing and retrieving the necessary data for the problem at hand, locating the correct information source (knowledge base) for a particular business constraint, suggesting specific models to use in "what-if" analysis, etc. The proposed SDSS comprises of the following intelligent agents: a) interface agent, b) task coordinator agent, c) model agent, d) web services agent, and e) data and knowledge agent. It is to be noted that while we currently envision the agent federation to encompass the above-mentioned agents, the architecture is "open" so that additional agents can easily be integrated into the system.

The *interface agent* provides mechanisms for the user to interact with the system. It enables the user to carryout various modeling and analysis tasks and renders the forms and reports created by the system as well as other outputs generated during data analysis and model execution. It also maintains user profiles and facilitates customization and parameterization of the tasks. The *task coordinator agent* serves as the controlling agent that takes care of the communication between the collaborating agents and coordinates the various tasks that need to be executed in order to solve the problem that the user is working on. This agent essentially drives the "what-if" scenario analyses. The *model agent* maintains meta-data about the various models that are part of the SDSS and provides interface to the model base and helps the user in model selection as well as execution. It responds to the coordinator agent by carrying out specific sub-tasks related to problem solving.

The *web services agent* maintains information about the various web services that are available and how to request for specific GIS services. It selects the appropriate web service by searching through the web services registry and takes care of the communication between the system and the web service. The *data and knowledge agent* provides access to relevant data and knowledge stored in various databases and knowledge bases that may be distributed throughout the organization. This agent maintains meta-data about the various data and knowledge sources and how to retrieve the necessary information based on the models being utilized.

Prototype Implementation

The proposed SDSS environment will be implemented as a web-based application using client-server architecture. This distributed environment will be built by extending the web-based SDSS system developed by the second author in a prior research project (Meyer et al., 2003). The client side is where a user interacts with the system through a web browser. The client side user interface is developed using JavaScript, HTML, and Active Server Pages (ASP). The prototype uses a simple Graphical User Interface (GUI) to dynamically create "user-friendly" HTML pages. Microsoft's Active Server Pages (ASP) technology is used because it is simple to implement, and allows the creation of dynamic pages to collect user input and session information required by the server-side processes.

A map display and report generator is being developed by customizing the Mapcafe Java applet that is a part of standard AvIMS. Mapcafe constructs and sends requests corresponding to user button and tool manipulations to the server-side application. The primary advantage of the Mapcafe applet is that it allows for customization using the Java programming language. Java language is used to develop visualization and decision support tools that will be placed on the MapCafe toolbar. The ArcView application running on the web server responds to the URL encoded requests received from the client by processing them and sending updated map images, text, and tabular data back to the requesting user's Mapcafe application, which renders the results graphically to the user.

The server side environment is where most of the actual functionality is being implemented. It includes a web server (IIS), ESRIMap web server extension (esrimap.dll), AvIMS, ESRI MapCafé Java applet, and ArcView GIS. IIS allows communication and transfers data between the client side (Web browser) and the ESRIMap Web server extension. AvIMS is an extension to ArcView GIS that allows ArcView to communicate with a Web server where ESRI's web server extension has been installed. Several GIS functions will be set up as Web Services and these services will be described using UDDI and will be accessed using SOAP messages. The agents will be developed using JADE, a FIPA-compliant agent framework (Bellifemine, 1999). The reasoning capability of the agents will be implemented using JESS, a forward chaining expert system shell written in Java (Friedman-Hill, 2003).

Summary

GIS and SDSS have traditionally been difficult to use because of the complex nature of spatial and temporal data representation, presentation, and computation. However, with the advances in the intelligent agent technology and web services, monolithic GIS systems can be made user friendly by providing intelligent interfaces. Intelligent agents can be deployed to help the user in accomplishing their spatial tasks. This paper has presented the architecture for an agent based SDSS environment, which incorporates web services and a variety of intelligent agents to guide the user in executing core business processes. Though we are in the early stages of implementation, the prototype is beginning to demonstrate the feasibility of implementing an effective agent-based SDSS environment.

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