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Introduction

Decision Support System (DSS) has been an important sector of IS research. Numerous studies have reported on various aspects of DSS such as nature, and effectiveness in decision making, framework/architecture, group support, etc. While various DSSs have been successfully used by upper management in decision making, a major limitation of these systems is their inability to handle spatial and temporal models/data.

GIS usage has resulted in large volumes of spatial data, and organizations see the need for incorporating this data into their analysis and decision making. Managers are beginning to understand the potential of using DSS and EIS that are enhanced with spatial and temporal capabilities in addressing issues related to marketing, demographics, routing, etc. Traditional GIS have lagged behind in providing tools that support upper management in decision making and cooperative problem solving. As pointed out by Keenan (1997), and Mennecke (1997), there are ample opportunities for cross fertilization of ideas from IS and GIS research in this regard.

Geographic Information Systems

GIS is capable of assembling, storing, manipulating, and displaying geographically referenced information, i.e., data identified according to their locations. Geographical information consists of both textual data ("attribute" or "aspatial" data) as well as spatial data (data which includes cartographic coordinates). Thus, a GIS not only provides users with tools for managing and linking attribute and spatial data, but also advanced modeling functions, designing and planning, and imaging capabilities.

Traditional GIS tend to be monolithic with proprietary display drivers, development tools, object models, database access, and user interface tools. All the layers in such a system are tightly coupled and generally not open to other systems. The necessity of finding new and faster ways of executing GIS tasks is a direct consequence of the development in the amount and quality of functions provided by existing packages. GIS users are under constant pressure to perform their tasks in shorter and shorter time frame, while the systems are getting more complex and cumbersome to use with steep learning curves. Any support that would decrease the burden on the user will be a welcome change. To this end, the use of intelligent agent technology may offer partial solutions to alleviate information overload, and carry out mundane and tedious tasks on behalf of the user.

Intelligent Agents

The concept of agent is becoming increasingly important not only in research, but also in commercial applications. Research on agents emerged initially from Distributed Artificial Intelligence, a branch of Artificial Intelligence that deals with the solution of complex problems by networks of autonomous, cooperating, computational processes called agents. Development of intelligent systems is on the rise in recent years (Hendler, 1996, Maes, 1996, Spector, 1997). These systems contain agents (intelligent computerized assistants) that are capable of acting autonomously, cooperatively, and collaboratively to achieve a collective goal.

Application of intelligent agents in the GIS environment is currently being explored and a few projects have reported positive results. Campos et al. (1996) describe an intelligent agent that provides an interface to ARC/INFO GIS to help the naive users better interact with the system. Rodrigues et al. (1997) report on developing intelligent agents for Smallworld GIS to help users with drawing and plotting tasks.

Spatial Decision Support

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. SDSS have been adequately covered in the literature (Densham, 1991, Moon, 1992, NCGIA, 1992) and a plethora of systems have been implemented to solve a variety of problems. Current focus is on designing distributed, adaptive decision support systems (Ferrand, 1996, Chuang et al., 1997) which are configurable, based on the problem at hand.

Researchers are beginning to investigate the use of intelligent agents in GIS-based decision support systems. Rodrigues et al. (1997) describe a multi-agent system called MA-MEGGOT, used for modeling geographic elements for environmental analysis and land use management. Gimblett et al. (1996) report on a system, which uses autonomous agents, to assist natural resource managers in assessing and managing wilderness settings. Kohler et al. (1996) describe an agent based system to model and study prehistoric settlements in north America.

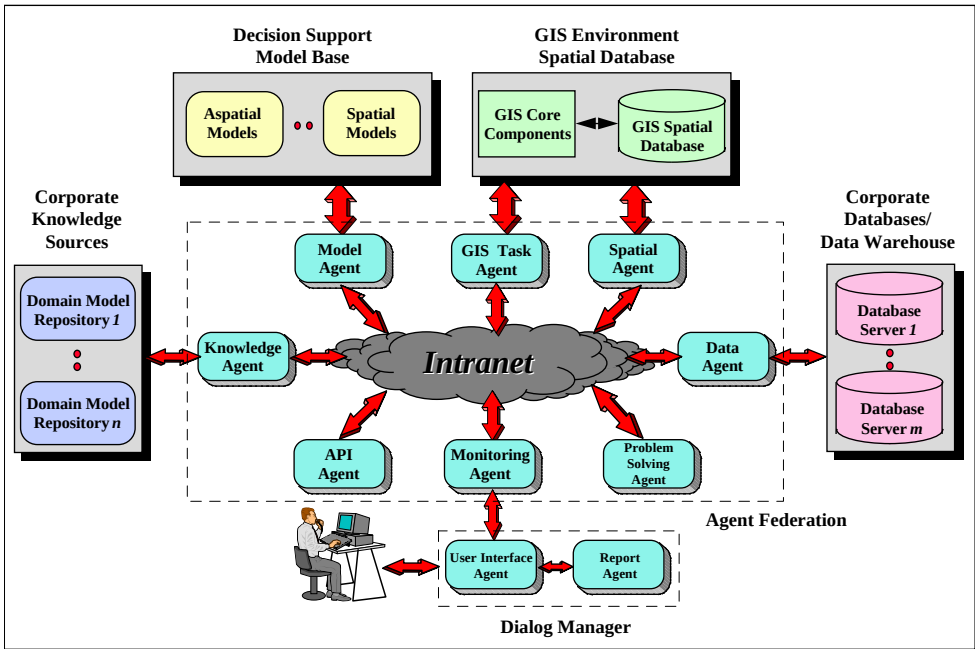

Figure 1. Architecture of Distributed Agent-Based Spatial Decision Support System

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.

Distributed Spatial Decision Support Environment

We extend the model suggested by Mennecke (1997) for "GIS as a decision support tool" in generating a model for our proposed SDSS environment. Conceptually, the proposed SDSS comprises of the following components: a) data management, b) model management, c) knowledge management, d) dialog management, and e) intelligent agent federation. The architecture of the SDSS is shown in Figure 1, where the different components are connected together by a corporate network. With the advances in internet/intranet technologies, we envision that this distributed environment could be implemented using a secure intranet, without having to install a proprietary network. The components of the SDSS are briefly described in the following paragraphs.

The data management component provides access to attribute and spatial data. It encompasses traditional databases, data warehouses, as well as GIS databases. In the proposed SDSS environment, we bring these databases "on-line," there by improving the accessibility of data. 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.

The knowledge management component consists 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. The dialog management component provides a graphical interface for the user to interact with the SDSS during a session. The interface is customizable based on the preferences of individual users.

Intelligent Agent Federation

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 for a particular business constraint, suggesting specific models to use in "what-if" analysis, etc. It is to be noted that while we currently envision the agent federation to encompass the following types of agents, the architecture is "open" so that additional agent types can easily be integrated into the system.

- ***User Interface Agent:*** Keeps track of user actions and acquires knowledge on tasks, habits and preferences of users. It can start and execute tasks on behalf of the user or suggest actions for them to take. It provides interface to SDSS, and facilitates problem solving.
- ***Report Agent***: Provides templates for generating and outputting different types of reports.
- ***Monitoring Agent***: Similar to control agents that monitor every event that occurs within the SDSS and channels the relevant information to other appropriate agents. It keeps track of the tasks/processes that are being executed, as well as the "state" of objects within the SDSS.
- ***Problem Solving Agent***: Performs the function of decision support. It is constructed as a goal-based agent so that it can correctly reach the desired state. It decomposes a task into sub-tasks and executes them in collaboration with other agents and then synthesizes the result.

- ***Knowledge Agent***: Provides interface to corporate knowledge sources that contain domain knowledge. It locates, and retrieves the relevant knowledge elements and communicates them to the problem solving agent.
- ***Model Agent***: Provides the interface to the model base and executes a specific model in solving a particular problem. It responds to the problem solving agent by executing a specific sub-task and communicating the results back.
- ***GIS Task Agent*****:** Automates a specific tool or a function of the GIS and helps the user in using that tool during problem solving. It basically encapsulates key functions of the GIS.
- ***Spatial Agent***: Can reason over representations of space. For a task with spatial characteristics, it accesses the necessary spatial information, and executes the necessary sub-tasks. It makes the spatial concepts computable.
- ***Data Agent***: Provides access to data stored in various corporate databases, data warehouses, and legacy systems. It provides relevant data sets to the problem solving agent during the course of a problem solving. It contains meta-data about data stored in different databases, and how to retrieve them.
- ***Application Program Interface (API) Agent***: API agent provides interface to other software systems that may be needed in problem solving.

Implementation

As a proof of concept, we are in the early stages of implementing a prototype agent-based SDSS environment; the intelligent agents are being developed using "JATLite" (Java Agent Template, Lite) from Stanford University. JATLite provides a template for building agents that can communicate over the internet/intranet. Agent communication is accomplished using KQML (Knowledge Query and Manipulation Language). Since JATLite provides a Java based agent platform, the agents are platform independent and hence portable, and mobile.

We are currently working with a large utility company that uses Smallworld GIS for managing their electrical and natural gas lines and related facilities. We are attempting to develop an SDSS environment to assist them in their planning and expansion activities. The SDSS environment is distributed over the corporate intranet to which a data warehouse, the GIS, and a knowledge base have been interfaced. The agents reside on different machines connected to the intranet.

Conclusion

Traditional DSS is inadequate in supporting spatial data/models and researchers are investigating ways to incorporate GIS techniques into DSS. However, such systems tend to be complex and inflexible. Use of intelligent agents to assist the decision maker in problem solving activities may obviate some of these problems. We have presented a conceptual model for a distributed intelligent agent-based SDSS, and are currently implementing a prototype environment to demonstrate the feasibility of such a system.

References

References available upon request from the author (sugumara@maple.lemoyne.edu)