Architecture of an Intelligent GIS

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Abstract

The aim of this paper is to analyze the possibilities of the integration of geographic information systems (GIS) and rule-based expert systems, and propose the outline of an integrated system architecture, based on client-server technics. Expert systems are one of intelligent system technologies that enables to make use of expert knowledge to solve problems. The integration of GIS and expert systems is an important activity that enhances the value of GIS. An example of integrating a GIS and experts system is presented. It was implemented by linking simple GIS software “Akis” to the CLIPS expert system shell.

Keywords: intelligent GIS, software integration, software architecture, middleware, expert systems.

1. Introduction

The aim of this paper is to analyze the possibilities of the integration of geographic information systems (GIS) and expert systems (ES), and propose the outline of an integrated system architecture. The integration of geographic information system and expert system technologies extends the possibilities of GIS. GIS are computer-based tools to capture, manipulate, process and display spatial or geo-referenced data. They contain both geometry data (co-ordinates and topological information) and attribute data, i.e., information describing the properties of geometrical objects such as points, lines, and polygons. Expert systems are one of intelligent system technologies that enables to make use of expert knowledge to solve problems. The knowledge is encoded in a computer program in the form of IF...THEN rules. New generation expert system tools combine rule-based and object-oriented knowledge representation, message passing, GUI, the ability to integrate with other systems. Usually, GIS enables to analyze quantitative spatial information, while expert systems enables to operate qualitative information, including incomplete knowledge. In qualitative reasoning, a situation is described by parameters that have a rather small predefined set of values, and by rules that use these symbolic values instead of numeric values. Linking an expert system with a GIS enables both the expert system and the GIS to perform new tasks, and opens the way for more flexible and complex analysis of spatial data, based on rules and logical inference.

Expert systems can be used in many GIS application domains. A number of examples from different domains of natural resources and environmental management are presented in [1]. Such systems combine models, GIS, and expert systems in a number of customized implementations for specific decision support problems.

Expert systems are often used to help configure models (implementing an experienced modelers know-how to support the less experienced user) and estimate parameters. A number of these “intelligent front end systems” or model advisors have been developed in the environmental domain [2].

The expert system technology can be useful in implementing spatial intelligent agents that would help to solve such problems as locating and retrieving spatial information in large networks (and specifically the Internet), facilitate the handling of a GIS user interface, implementing improved spatial tasks and creating interfaces between GIS and specific software packages [3].

In [4], it is proposed to use rule-based knowledge for more intelligent visualization of maps. According to the authors, an intelligent GIS should assist the user in the analysis, and this presupposes the following capabilities: the capability to understand user’s information-seeking
goals, the capability to select and visualize appropriate data in a way productive for achieving these goals, and the capability to support the user’s analytical activity with the use of the generated presentations.

Depending on the problem addressed, on uses and users, various levels of integration are possible, ranging from the simple exchange of data files to a complete integration within one common environment, framework, and user interface.

Section 2 overview methods of integrating GIS and intelligent system technologies. In section 3, the outline of an architecture for integrating a GIS and expert system based on client-server technics is proposed, and an example of integrating a GIS and expert system is presented. In section 4, conclusions are presented.

2. GIS integration with artificial intelligence technologies

The problem of integrating GIS and different intelligent systems technologies (including expert systems) was investigated in many works [5; 6]. It can be summarized, that existing approaches to addressing the problem of integrating GIS and other software range from tightly coupled systems to loosely coupled systems.

In tightly coupled systems, expert system components exist as specially coded modules within the framework of a GIS. Such modules might be written in a language provided by the GIS. This effectively extends the functionality of GIS and provides seamless integration from a user interface viewpoint.

Loosely coupled systems interact by using files to exchange data between a GIS and other systems. The expert system application may read some of its input data from GIS files, and produce some of its output in a format that allows processing and display with GIS. It requires little if any software modifications but the speed of data transfer between the expert system and the GIS is low and it is difficult to implement a common user interface (for example, point-and-click operations).

Making an independently developed software systems communicate often requires the system to be “wrapped”, i.e., a piece of software is developed that communicates to external processes as well as controlling the systems being integrated. Wrappers are common components in a number of software architectures used for integrating software [7; 8]. The wrapping software provides a shell around the software to be integrated, providing a point of access to the integrated software.

Recent GIS implementations have begun to support the use of client-server technics as an effective means of transferring data while retaining data structure. This has presented the possibility of linking other systems with GIS by using these technics. In [9], a co-operative approach is described, based on client-server technologies. The authors present two types of this approach. First, with direct co-operation, systems being integrated are directly linked via interapplication communication. Secondly, indirect co-operation is characterized by the existence of an intermediate interface between systems. A workbench would be an example of such an interface.

3. Architecture

It is reasonable to take into account the OGIS (Open Geodata Interoperability Specification) architecture [10] when integrating GIS with other systems, because it enables application domains to interoperate with geodata stores and geoprocessing services. The OGIS guide identifies several software layers in the design of integration software. These include the presentation layer, the application layer, the application server layer, the spatial data access provider layer, the database layer and the hardware and network layer. OGIS unify geodata models and geoprocessing services.

We propose an architecture for integrating a GIS and expert system that is compatible with the OGIS model and supplements it with an expert system shell and knowledge bases. The architecture is based on client-server technics. Servers are components that provide a response to a specific
client request for service or data. Clients can also be servers by providing service to higher order clients. Every construct in this architecture is an object. Each has specific interface methods, which allow it to communicate with other objects.

The components of the integration scheme are (Figure 1):

- GIS applications,
- GIS service providers,
- Expert system shell,
- Spatial data access providers,
- Spatial databases,
- Knowledge bases.

![Figure 1. The general integrated system architecture](image)

Spatial (geometric and attribute) data can be stored in databases of different types or in files of different formats. To process them, intermediate software, called “spatial data access providers”, is used. Spatial data access providers standardize data access. They bidirectionally translate application semantics and database semantics. For example, an application will be able to send the query to the database in terms of a particular geodata model, whereas the database understands only SQL or a proprietary query language. GIS service providers are software components that provide a response to a specific client request for service. They include a set of common GIS functions to access, search, analyze, visualize and process in other ways spatial data.

The expert system shell makes inferences using knowledge stored in knowledge bases. It includes an inference engine, and interface modules that ensure interaction with spatial data access providers and GIS service providers. Besides, the expert system shell provides its clients with programming interface. This architecture enables to implement specialized GIS applications that use an appropriate part of GIS services and the expert system shell with appropriate knowledge bases. Filling the expert system shell with knowledge makes it an expert system in a certain field. By replacing knowledge bases, we get another expert system, which uses the same knowledge representation methods and inference engine.
In the proposed architecture, there are two ways to implement GIS and expert system integration: an expert system shell can be embedded into a GIS application, or a GIS application and expert system can run in separate processes.

### 3.1 Embedded expert systems

One or more objects of the expert system shell can be created in a GIS application. It can operate an expert system shell by using the shell object's properties and methods, and receives notifications from the expert system shell in the form of events. Figure 2 demonstrates this interaction. Properties allow the client change certain values of the expert system shell, or make requests of the shell, such accessing a specific piece of data that the expert system shell maintains. A method is a procedure that is exposed by the expert system shell and performs a specific action (for example, runs the inference engine). Events are used to notify the client when something important happens in the shell (for example, event fires just before a fact is asserted). The expert system shell can send additional information about an event to the client by attaching parameters to the event.

![Diagram](image.png)

**Figure 2. Interaction between a GIS application and ES shell**

### 3.2 Communication between a GIS application and expert system

In some cases, a GIS application and expert system should run in parallel in separate processes. In such a case, the message passing can be used for the interaction of the GIS and expert system. Each application has its own queue of received messages and retrieves them when ready. Message passing is managed by a message queue manager. Messages are being sent asynchronously, just putting them into the receiver's queue. The calling system is free to continue processing or wait depending on its own needs. Hence, the communication can be synchronous or asynchronous.

A client's process initiates conversation and requests certain services from the server. The applications exchange data by any or all of the following methods:

- **Manual link**: the client must request data from the server (or send command).
- **Warm data link**: the server notifies the client that specified data have changed.
- **Hot data link**: the server automatically sends data whenever data change.

Depending on which one is a server and which one is a client, there are two possibilities (see Figure 3). If the GIS application is a client, and the expert system application is a server (Figure 3a), then expert system can perform the monitoring of external events and notify the GIS application. For example, in the automatic vehicle location system, it can receive and process data from external devices, identify from what vehicle the message is received, determine its co-ordinates and other parameters (time, course, speed, etc.) and pass data to the GIS application, which visualizes changes of the vehicle's location.

If the GIS application is a server, and the expert system application is a client (Figure 3b), then the GIS application can pass messages about events to the client. For example, when a user selects an object on the map or clicks a button, the expert system application is informed about these events and can react to them. This enables to integrate the GIS user interface with the expert system.

In case of the complete integration, a GIS and expert system should act as both a client and a server, depending on the situation.
3.3 An example of implementation

To demonstrate the GIS and expert system integration, an experimental system was developed that integrates GIS “Akis” and expert system shell CLIPS. “Akis” is a simple GIS program with main GIS functions (map visualization, creating of layers and objects, search, measuring, etc.) [11]. CLIPS is a forward chaining, multiparadigm, expert system shell that provides support for rule-based, object-oriented, and procedural programming [12]. Basic elements of expert systems, also provided by CLIPS are a fact and instance base, a rule base, and an inference engine. The rules are of the following form:

\[
\text{IF } \text{[conditions]} \text{ THEN } \text{[actions]},
\]

and specify a set of actions to be performed for a given situation. There can be such actions as the creating of a new fact, function call, message sending to an instance and so on. The following CLIPS extensions were implemented:

- Definitions of classes used in GIS data model (Geoobject, Point, Line, Polygon, etc.) were created. They are stored in a knowledge base and their instances can be created.
- A communication subsystem was created. It includes two modules: a server part and a client part. The server part processes client's queries and commands, answers queries and sends messages about events. The client part sends queries and commands to the server, processes answers and messages about events.
- External functions were attached that enable to use GIS functions.

4. Conclusions

In this paper an architecture for integrating a GIS and expert system is described. It is based on the client-server model and takes into account the OGIS specification. The architecture enables to implement systems using reusable components, and create domain-specific GIS applications including an appropriate part of GIS services and the expert system shell with appropriate knowledge bases. To implement this architecture completely, the expert system shell must be able to run as a server for client applications as well as a client of GIS services providers and spatial data access providers. To this aim, an expert system shell meeting these requirements should be created, or an existing expert system shell should have appropriate extension possibilities. An experimental system demonstrating the integration of a GIS and expert system is described.
5. References


