GIS APPLICATIONS USING AGENT TECHNOLOGY

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ABSTRACT:

There is an increasing interest in agent-oriented technology, spanning applications as diverse as information retrieval, user interface design and network management. Application of intelligent agents in the GIS environment is actively being explored. Many different types of agents are being employed to improve usability of GIS software as well as users access to geospatial data and services available through Internet. Geospatial information retrieval and filter, intelligent geospatial search engine, knowledge discovery, decision model assessment and optimization are typical applications based on using agents in GIS.
This paper presents a short introduction to agent and the main research areas in agent technology. The heart of the paper is a wide overview of applications of intelligent agents in GIS. These applications have been clearly classified in different categories. The paper concludes with an example of a web search tool, Special Spatial Search (SSS). SSS is developed to assist users in geospatial related searching over the web.

1. INTRODUCTION

Over the past two decades, GISs have been adopted widely in support of planning, agriculture, forestry, infrastructure maintenance, and many other fields. Distributed Geospatial Information (DGI) is the widespread distribution of geospatial information in a variety of forms, including maps, images, data sets, analysis operations, and reports. Distributed Geospatial Information Systems (DGIS), are the systems that provide DGI through Internet.
Nowadays, the Internet has become a huge source of Geospatial information and offers already many different services. The advantages of using such technology are obvious to most users of geodata and geoprocessing resources. However, effective use of information in web is becoming increasingly difficult because of the sheer size of the web and its diversity of resource, thus intelligent software technology for DGIS needs to be developed. Moreover the development of GIS technology has made it available to a growing number of people from different disciplines and with different backgrounds. However, the degree of productivity they can achieve is limited by their lack of technical knowledge about GIS tools, which are becoming larger packages with more functionalities. A better user interaction is a key issue to get a broader user acceptance of GIS. The user interface is probably the most important aspects of GIS usability. Therefore GIS software intelligent interface could be an ideal tool to help the users of GIS software in this quickly changing environment.
Application of intelligent agents in the GIS environment is actively being explored and some projects have been reported in the literature where different types of agents are being employed to improve usability of GIS software as well as users access to geospatial data and services available through Internet. Geospatial information retrieval and filter, intelligent geospatial search engine, knowledge discovery, software intelligent user interface, decision model assessment and optimization are typical applications based on using agents in GIS.
In the following section, we present a short introduction about agent and the main research areas in agent technology. In section 3, some of the projects and researches regarding the application of intelligent agents in the GIS environment will be overviewed. Section 4 describes the developed web search tool, Special Spatial Search (SSS). SSS is developed using HTML and Java Scripting to assist users in geospatial related searching over the web. The final section offers some concluding remarks.

2. AGENT TECHNOLOGY

Intelligent Agents are one of the "hot" topics in Information Systems R&D at the moment. The last ten years have seen a marked interest in agent-oriented technology, spanning applications as diverse as information retrieval, user interface design and network management.
An agent has been defined as a computational entity which:
- acts on behalf of other entities in an autonomous fashion;
- performs its actions with some level of proactivity and/or reactiveness;
- exhibits some level of the key attributes of learning, co-operation and mobility.

In the above definition of agent,
- “autonomy” means operating without the direct intervention of humans or others;
- “reactivity” means reacting on events in the environment;
- “proactivity” means exhibiting goal-directed behavior by taking the initiative.

2.1 Software Agents

Software agents (often simply termed agents) are software systems that inhabit computers and networks and assist users with computer-based tasks. Why the need for software agents is becoming so urgent? The computer is merely a passive entity waiting to execute specific, highly detailed instructions; it provides little help for complex tasks or for carrying out actions that may consume a large proportion of the user's time (e.g., searching for information). Researchers and software companies have set high hopes on software agents, which know users' interests and can act autonomously on their behalf. Instead of exercising complete control, people will be engaged in a cooperative process in which both human and computer agents initiate communications, monitor events and perform tasks to meet users' goals. In essence, we need software agents because (Green, et. al, 1997):

- more and more everyday tasks are computer-based;
- the world is in a midst of an information revolution, resulting in vast amounts of dynamic and unstructured information;
- increasingly more users are untrained;
- and therefore users require agents to assist them in order to understand the technically complex world.

2.2 Main Research Areas

The researches in agent technology have been focused on three research areas, namely, Intelligent User Interfaces, Distributed Agent Technology and finally, Mobile Agent Technology. The following three subsections will briefly summarize the main aspects of these areas in turn.

2.2.1 Intelligent User Interfaces: Intelligent User Interfaces (IUI) attempt to maximize the productivity of the current user's interaction with the system. Intelligent (User) Interface Agents are fairly recent developments that use an agent-oriented approach to the construction of such systems. The major factors that distinguish Interface Agents from any other IUI is the fact that agents are proactive and enjoy a degree of autonomy. Generally the existing interface agents can be classified in three categories, namely, information filtering agents, information retrieval agents and personal digital assistants.

2.2.2 Distributed Agent Technology: Distributed Artificial Intelligence is a sub-field of Artificial Intelligence which is concerned with a society of problem solvers or agents interacting in order to solve a common problem. Such a society is termed a Multi-Agent System (MAS), namely, a network of problem solvers that work together to solve problems that are beyond their individual capabilities. Multi agent systems have the following advantages (Purvis, et. al, 2000):

- Using a collection of problem-solvers makes it easier to employ divide-and-conquer strategies in order to solve complex, distributed problems. Each agent only needs to possess the capabilities and resources to solve an individual, local problem.
- The mental image of autonomous, human-like agents facilitates the mapping of real-world problems into a computational domain.
- The idea of several agents cooperating to solve a problem that none could solve individually is a powerful metaphor for thinking about various ways that individual elements can be combined to solve complex problems.

2.2.3 Mobile Agents: Mobile agents simply are programs, which may autonomously migrate themselves from host to host in a computer network on behalf of their users. Mobile agent leaves its computer to `go' directly to the machine offering the service. There it invokes all the operations locally and also processes the results locally, avoiding all the network traffic. Only when its job is finished does it return to its ``home machine". There are several advantages resulting from the mobility of the programs, depending on their purpose.

3. APPLICATIONS OF AGENTS IN GIS

Over the past two decades, GISs have been adopted widely in support of planning, agriculture, forestry, infrastructure maintenance, and many other fields. Together with the use of the World Wide Web (WWW), GIS could be further developed to allow many more people to have access to GIS functionality and to enhance community participation in planning. The advantages of using such technology are obvious to most users of geodata and geoprocessing resources. Because it can be very time consuming for people to cope with the overwhelming amount of data, agents could be an ideal tool to help the users of Geospatial data and services in this quickly changing environment. Agents can also be used to make GIS user interface intelligent so that non-expert users may use the GIS software more easily.

Geospatial information retrieval and filter, intelligent geospatial search engine, knowledge discovery, decision model assessment and optimization are typical applications based on using agents in GIS. The following subsections briefly describe some applications of agent technology in GIS.

3.1 GIS Software Intelligent User Interface

The development of GIS technology has made it available to a growing number of people from different disciplines and with different backgrounds. Assuming that the user is neither familiar with GIS software, nor with the content and structure of its database, an intelligent interface agent should be able to help GIS software users to retrieve the information they want, build or help them to build complex queries during the interaction.

3.1.1 Web Based Intelligent Interface To GIS Using Agent Technology: There are many instances where GIS users do not perform complex operations using a GIS application, and also don’t have to write to GIS databases constantly. They simply want to access certain data elements from the GIS database in order to carry out their day to day tasks so it is sufficient for user to have read only access to GIS data. More over, there is a major push towards providing web access to GIS data; using a simple browser interface user can quickly gain access to GIS data without having to run complex GIS applications.

Sugumaran (1999) has proposed an agent based GIS environment where several types of intelligent agents coexist in a distributed environment, and these agents collaborate with one another in solving a particular problem. These agents guide the user in executing core business processes and the GIS can also be augmented with Web interface to improve access to spatial data. The following generic agents are defined for this GIS environment (Sugumaran, 1999):

- User Interface Agents: These agents keep track of user actions and acquire knowledge on tasks, habits and preferences of users. They can start and execute tasks on behalf of the user or suggest actions for them to take. They constantly learn the user preferences and profile and build a knowledge base of the way in which he/she works and also modify the user environment according to his/her preferred tools, or the commands that are executed the most. The user environment will constantly and dynamically evolve over time.

- Monitoring Agents: These agents monitor every event that occurs in the GIS and channel the relevant information to other appropriate agents. They keep track of the tasks/processes that are being executed within the GIS system and keep track of the state of objects within the GIS environment. When a specific event or user action causes the state of an object to change, the affected parties are notified.
- Business Process Agents: They help the end users with the execution of typical business processes that the user is responsible for.
- Application Program Interface (API) Agents: These agents provide interface to other software systems that may be needed in problem solving. They serve as interfaces between the GIS and external software packages like statistical packages, generalization algorithms, spatial models, etc.

One of the typical applications of this system is assisting a utility company in providing electric and gas connections to new customers (Sugumaran, 1999).

3.1.2 Interface Agent For ArcEdit: Clover Point Cartographics Ltd. , which is a GIS and resource consultants to business and government has developed a new Windows-like graphic user interface simplifying start-up for ArcEdit users. It is called Personal Edit Agent (PEA). This agent provides a start-up interface similar to Microsoft Windows Explorer; allowing user to browse through familiar directories to find the desired coverage, then open it into a standard ArcEdit session.

3.1.3 Interface Agent for ArcInfo: Campos et. al. (1996) have developed a knowledge-based interface agent whose mission is to help users without a knowledge of ArcInfo to access and process spatial data stored in ArcInfo databases. In order to help the user, the agent must be able to:

- Build sequences of ArcInfo commands that provide answers to typical queries to an ArcInfo database,
- Infer, if it is possible, best matches between user's concepts and ArcInfo data, and generate text and graphical output to the user.

Assuming the *request* - *response* model of interaction between a user and ArcInfo, the task of the interface agent is to (Campos, et. al, 1996):

- interpret user's request,
- translate it into ArcInfo command(s),
- receive some results back from ArcInfo, and
- present them to the user.

In order to convert user's input into sequences of ArcInfo commands, the agent must have *plans* - sequences of actions, which are taken if their preconditions are satisfied, for every type of user request. Representations of plans are stored in a semantic network knowledge base (the system's knowledge base), and used to translate natural language queries, plan definitions, and requests to sequences of ArcInfo commands. In summary the interface agent, using a client-server schema and operating on a LAN or WAN network, receives and processes requests written in plain English, interacting with the user in case of possible mismatches between his/her concepts and the representation of data in the ArcInfo database. The agent builds and sends sequences of commands oriented to provide the information requested by the user to an ArcInfo server, receives, and presents the results of those requests to the user. Campos et. al. (1996) have built a prototype of the interface agent using SNePS (Semantic Network Processing System) and Common Lisp on a Sun Sparc station.

3.2 Making Depositories of Geographical Data Usable with Intelligent Agents

Sengupta and Bennett (2001) have used autonomous agents to make the depositories of geographical data more usable. Considerable insight is often gained when multiple thematic layers are incorporated into the analysis. When such techniques are applied, however, it is assumed that all data:

1) Share a common and appropriate geographical referencing system;
2) Cover a common and appropriate geographical area;
3) Contain non-spatial attribute data of interest; and
4) Are stored in a format that can be read by the selected analytical software.

However, geospatial data stored in network accessible depositories are stored in a variety of proprietary formats, cover varying spatial extents, have different levels of spatial accuracy, map to a variety of geographic referencing systems, and contain a vast and disparate array of attribute data. It is often necessary, therefore, to apply a sequenced set of data transformations to produce a spatial database that contains the desired spatial and attribute information in a consistent and usable format. Finding applicable data and performing the necessary data transformations can be a time consuming task that requires significant expertise in geo-processing technologies. Thus, the need for such transformations places real limits on network-based data mining and exploration.

Sengupta and Bennett (2001) propose the process called “data fusion” to automate the integration of disparate datasets into consistent geographical datasets that are suitable for analysis by users or by data mining technologies. In their presented system, users of data rich digital environments are assisted by *Intelligent Agents* that search for relevant data and analytical tools and *"fuse*s" these resources into usable information.

3.3 Using Mobile agents in GIS

The inevitable trend of information technology is to make things popular and easy to use. However, effective use of information in web is becoming increasingly difficult because of the sheer size of the web and its diversity of resource, thus intelligent software technology for DGIS needs to be developed. Today new mobile agent-based products are introduced in different application areas including DGIS.

GeoAgent (Wu, et. al, 1999), which is one of the mobile agents introduced in geospatial information field inhabit distributed networking environments (e.g. Internet), sense and act on the environments with different appearances, to realize intelligent acquirements, processing, storage, exploration, presentation and decision-making support for geospatial data. This agent has been defined as “an evolutionary intelligent agent with geospatial reasoning ability by utilizing geospatial knowledge” and it possesses the following new properties besides sharing the general properties of agents (Wu, et. al, 1999):

- Geospatial reasoning ability: This ability is based on a geospatial knowledge base and a geospatial reasoning mechanism. Having access to a geospatial knowledge base is necessary because in distributed networking environments, it is not practical for each agent to own its exclusive knowledge base since it will consume system resources so much and cause consistency maintenance problems of knowledge base.
- Evolutionary ability: This ability makes the agent adaptable to changing environments efficiently.

- Mobile ability: Agent travel from one machine to another in public networks securely. This ability enables agent to process data at the data source, rather than fetching it remotely, allowing higher performance operation and reducing network connection time and costs.
- Collaboration: Agent has the ability to cooperate with other agents efficiently and intelligently.

3.4 Agent Mediated Links between GIS and Spatial Modeling software

Spatial Decision Support Systems (SDSS) are designed to provide support for the analysis and evaluation of spatial problems. One method of developing a SDSS is to extend the functionality of existing GIS to incorporate analytical and simulation modeling software needed to solve a particular set of spatial problems. Sengupta et. al. (1996) have proposed a new method of linking GIS and analytical models. The links are implemented using agents that communicate via a modeling language, referred to as Model Definition Language (MDL). The MDL provides an inter-agent communication protocol for cartographic modeling. The design of the geoprocessing system contains five classes of agents: the user interface agent, the model search agents, the spatial modeling agent, the data search agents and the Spatial Operator Implementation Agents (SOIAs). Each class of agent has a specific function to perform in sequence once the user starts the modeling process. MDL constructs represent spatial operators that the agents use to query, retrieve, manipulate and store geographical datasets and spatial modeling software.
Sengupta et. al. (1996) have also proposed a conceptual framework for the development of a Distributed SDSS where the simulation software and required datasets, as well as the GIS may be located on multiple machines and agents are equipped to search, retrieve and put together appropriate data using the WWW. This system would utilize the computing power and storage capacity of several machines to make advanced geoprocessing capabilities more generally accessible. The users could interact the user interface agent on their machine, while additional agents search for datasets and simulation software distributed on the Internet. Current network technology provides the support for the development of such a distributed system thus agents implemented as objects can be transferred between machines during their searches. This conceptual framework can potentially be very useful for the novice GIS user with little system resources (in terms of hardware and software) and enable him/her to access more computational power and data available over the network.

3.5 Automated Map Generalization Using Agents

Generalization is the process that aims at simplifying geographical information to make it meet the users' needs. Generalization enhances of important information and removes of unnecessary one. That process concerns entities (preservation, removal or grouping of objects) and their geometry (preservation or removal of geometric information such as location or shapes). In automated cartography, most of the developed map production systems are complex and tedious to use, and require user intensive interaction and guidance during the design process. AGENT project on multi agent systems in cartography [14] is driven by the objective to address such shortcomings. In this project, agents in three levels are considered (Lamy, et. al, 1999):

- *Micro agents* manage the generalization of individual geographic phenomenon (such as Building);
- *Meso agents* manage groups of objects (such as District);
- *Macro objects* are at a coarser scale still, involved in the broad scale issues of map design (such as town).

Agents can become *active* when they act autonomously and chose the way to generalize by themselves or *reactive* when they are ordered by an upper-layer meso-agent. In the first case, agents have a number of methods in order to implement them as autonomously acting entities generalizing themselves and their map environment. Alternatively they can obey orders to execute plans given to them by organizations.
In an autonomous state, an agent aims at reaching its own goals that means to satisfy a set of constraints: its current "happiness" will therefore depend on the current degree of satisfaction of its constraints.
A violated constraint will be able to propose a set of behaviors to solve its violation. An agent can therefore receive a list of possible actions coming from its set of constraints. As the behaviors that are proposed by one constraint can infer another violation of constraint (to increase size damages accuracy), agent must own decision capabilities to choose and trigger one behavior. That choice is crucial and that procedural knowledge is encapsulated in the agent structure. It depends on a set of parameters which are related both to map specification and to the current state of the agent. The chosen action is triggered and the new state of the agent in respects to its constraints is re-evaluated. However the chosen solution can fail and another one can be tried through a backtracking process.

3.6 Defining the Correctness of Maps Using a Multi-Agent Simulation

Frank (2000) has used a multi-agent formalism to produce a model of map production, map communication and map use. Frank (2000) considers a small task; namely, the production and use of a small street network map for navigation. The model constructed simulates:

- The environment, which is a small part of a city street network;
- A map-maker who explores the environment and collects information, which he uses to construct a map of the area; and
- A map-user who acquires this map to gain knowledge, which he uses to navigate in this environment.

The environment represents the world in which persons live and the agents represent the persons who make and use maps. The simulation includes multiple agents – at least one map-making agent and one or several map-using agents. The approach is to model the complete process, which starts with data collection in reality, produces the map and then the process of map use: reading the map to navigate in an unknown territory. The model uses a two-tiered *reality* and *beliefs* representation, in which reality (facts) and the agents' cognition (beliefs) are represented separately.
The followings summarize the agents' tasks and the procedure of map quality assessment in this simulation (Frank, 2000):
<u>Map Making Agent:</u> The map-making agent is a specialized agent and explores first the environment and then draws a map. This map is then given to the map-using agent.
<u>Map-Using Agents:</u> The map-using agents have the task of moving from the node they are located at to another node in the environment. They intend to travel the shortest path (minimal distance). A map-user first reads the map and adds the knowledge acquired from the map to his set of beliefs about the environment before he plans the shortest path to his destination node.

<u>*Maps:*</u> Maps are artifacts, which exist in the environment. The map-making agent produces the map usually after he has collected all beliefs about the environment. The map represents these beliefs in a (simulated) graphical format. Maps are simulated in the model as a list of line segments (with start and end map coordinates) and labels at the intersection coordinates; one can think of this as suitable instructions for drawing a map with a computerized plotter. The map, in the form of the drawing instructions, is then read by the map-using agent and translated into a list of beliefs.

<u>*Map Quality Assessment:*</u> A map is correct if the result of an operation based on the information acquired from the map is the same as if the agent would have explored the world to gain the same information. The proof is in two steps: completeness and correctness. *Completeness* assures that all relevant elements – here nodes and segments – are transformed between the respective representations. The construction of the beliefs of an agent about the environment can be seen as a transformation between two data structures: the data structure, which represents the environment, is transformed into the internal structure of the beliefs. Similarly is the construction of the map a transformation between the data structure of the agent's beliefs into the list of drawing instructions; reading the map is the transformation of the data element of the map into beliefs. These transformations should be applied to all elements and nothing should be 'overlooked'. *Correctness* requires that the transformations preserve the properties important for the decision (in this case the determination of the shortest path). A street segment is added to the beliefs after it is traveled; having traveled the segment ensures that the segment is viable and the cost is the cost just observed. Map-makers translate each segment into a line drawn. The positions are based on the observed coordinate values for intersections. Map-users read the drawn line as viable segments and use the length of the line as an indication of the cost. These operations guarantee that beliefs about viable street segments by the map-maker are communicated to the map-users.

4. SPECIAL SPATIAL SEARCH TOOL

A web search tool, Special Spatial Search (SSS) is developed using HTML and JavaScripting to assist users in geospatial related searching over the web. The following sections describe about three facilities provided by this tool.

4.1 Intelligent Dictionary Search Tool

This tool assists user to use a GIS dictionary more easily and efficiently. User enters a word or phrase or even a sentence to get the exact match or related items in the dictionary. The on-line GIS dictionary provided by Association for Geographic Information is used and related items in that dictionary are shown in a window. User may get more than one item and can select each one to get its definition. The followings are some more details about Intelligent Dictionary Search Tool, explaining its intelligence and advantages with respect to using on-line GIS Dictionary itself:

- When using on-line GIS dictionary itself, if user enters a sentence such as "What is map?" or "I want to know about map", no match will be found. But using this intelligent tool all matches with the word "map" will be listed and all other non-keywords such as "what", "is", "I", "want", "to" will just be ignored.
- When using GIS dictionary itself, if user enters two keywords such as "map accuracy" or "map and accuracy", no match will be found if these combinations are not available in the dictionary. But using this intelligent tool all items matching with "map" and "accuracy" will be listed.
- User can search for only one item at once, when using on-line GIS dictionary. But using this intelligent tool, user can search for more than one item at once, just by typing the word "and" between them or just leaving a space between words.
- Using on-line GIS dictionary, if user enters "Base Mapping" will not get any matching. But using this intelligent interface user will get "Base Map" as a matched item.

4.2 Advanced Search Engine Tool

Using this tool, user can search for one or more geospatial related item(s) over the web. Geospatial related items are divided to 6 categories and each category is associated with a pull down list containing some related items. Following facilities are provided for user to search more easily and efficiently (See Figure 1):

- Selecting one or more geospatial items from the pull down lists;
- Combining a string search with the category search;
- Excluding any pages that contain special word or phrase;
- Excluding or including only pages from special site or domain;
- Selecting pages written in one of twelve languages or in any language;
- Selecting number of results to be shown in one page (10, 20, 30, 50,100);
- Going back to the main page of SSS.

This tool uses Google search engine to search the Web. Generally, when we search for terms such as "interpolation", "filtering", "resampling", classification" , as these general terms used in different disciplines, so the result of our search will contain many undesired pages. However, using the Advanced Search Engine Tool, the result will just contain geospatial related pages.

One of the other advantages of this tool is that if we search for a phrase such as "Digital Terrain Modeling" it will also search for its abbreviation "DTM" and if we search for the word "generalization" it will also search for "generalisation".

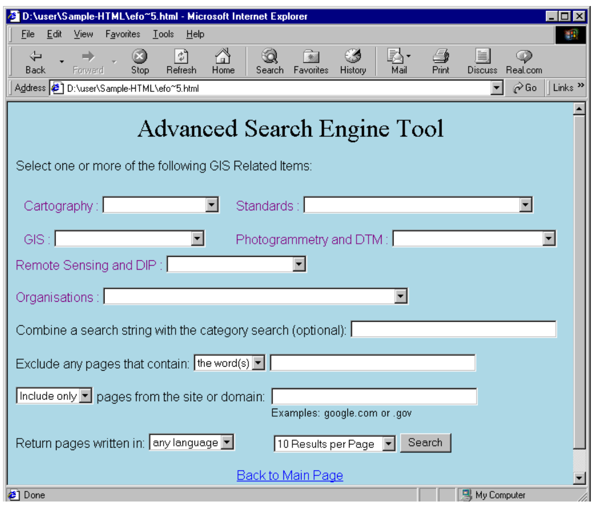

Figure 1: Advanced Search Engine Tool

4.3 Advanced Journals Search Tool

Using this tool, user can search in one or more geospatial related journal(s) more efficiently. Sixteen journals are available to select by the user. This tool uses Google search engine [17] to search the Web. Following facilities are provided for user to search more easily and efficiently (See Figure 2):

- Selecting one or more geospatial Journals;
- Typing a string to be searched within selected journal(s);
- Excluding any pages that contain special word or phrase;
- Selecting pages written in one of twelve languages or in any language;
- Selecting number of results to be shown in one page (10, 20, 30, 50,100);
- Going back to the main page of SSS.

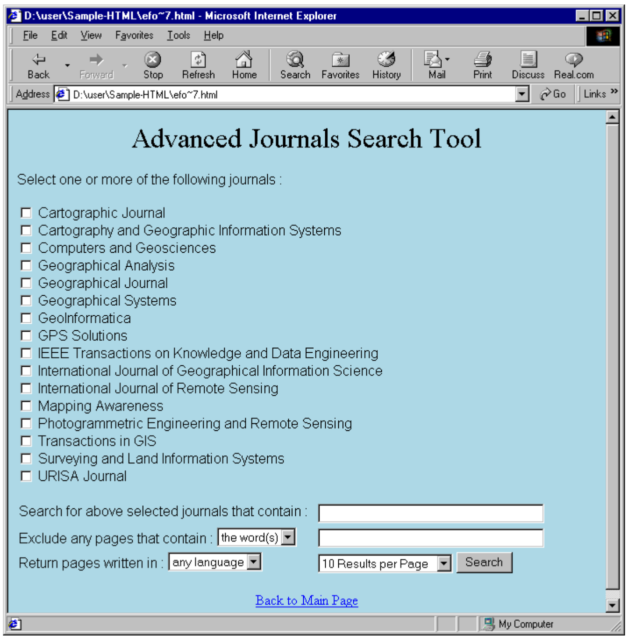

Figure 2: Advanced Journals Search Tool

One of the advantages of this tool is that user doesn't need to remember the URL address of the journals, what he/she needs is just selecting them from the list. The other advantage is that, two or more journals can be searched simultaneously. Although this tool provides user with 16 journals, however more journals can easily be added.

5. CONCLUSIONS

With the use of the World Wide Web (WWW), many people from different disciplines and with different backgrounds have access to GIS functionality. However, the degree of productivity they can achieve is limited by their lack of technical knowledge about GIS tools. Assuming that the user is neither familiar with GIS software, nor with the content and structure of its database, an intelligent interface will be able to help GIS software users to retrieve the information they want, build or help them to build complex queries during the interaction. Moreover the Internet has become a huge source of Geospatial information and offers already many different services. However, effective use of information in web is becoming increasingly difficult because of the sheer size of the web and its diversity of resource, thus intelligent software technology for DGIS needs to be developed. Application of intelligent agents in the GIS environment is actively being explored and some projects have been reported in the literature where different types of agents are being employed to improve usability of GIS software as well as users access to geospatial data and services available through Internet.

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