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Towards Collaborative Spatial Decision Support In A Web-Based Environment

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ABSTRACT

Spatial decision-making in a distributed environment involves access to data and models from heterogeneous sources and repositories to compose disparate services into a meaningful integration. This is especially true in environmental planning which requires collaborative decision-making where complex interacting agents with conflicting goals need to work in a distributed environment. This paper identifies research issues on spatial decision-making in the context of distributed geo-spatial data warehouse. Emphasis is being put on the access to model description to ensure model and data interoperability in a distributed environment. We illustrate a Web based Spatial Decision Support System GEO-ELCA (Exploratory Land use Change Assessment), which is designed to assess the hydrological impact of land use changes. The system allows explorative evaluation of pollution scenarios in response to user's decision to change land use from one category to another.

INTRODUCTION

The vision of geo-spatial data warehouse or geo-libraries challenges the fundamental criticism directed against Geographic Information Systems (GIS) being "too elitist" tool that harbor the gap between system users and non-users (Pickles, 1995). In the recent years, there has been a growing interest in the distributed access to geospatial information and services to decision makers and planners to promote Collaborative Spatial Decision Making (CSDM). CSDM and public GIS, often called GIS2 (Densham et al., 1995; Sheppard, 1995) involves a "bottom-up" planning model reflecting the stakeholder's perspective to explore the scientifically projected planning scenarios. The development of Internet brings closer involvement of multiple stakeholders from different geographic locations and social orientations to explore diverse spatial planning tools and Web services to extract spatial data and models from the online repositories and contribute in complex decision-making. The paper reviews research issues on collaborative decision making within the context of distributed GIS services involving Geolibraries or Geospatial data warehouse for spatial decision-making.

COLLABORATIVE SPATIAL DECISION MAKING

Decision making for environmental planning is inherently distributed in nature over the space and time. It presupposes multiple collaborative agents with different perspectives working together in a complex emergent environment. These agents must have an integrated data access from heterogeneous sources to integrate with transparent high performance computing resources to compose decision models dynamically. However, in real life situation, it is often difficult to achieve the stakeholder's views or effective pattern of social interactions because of heterogeneous group behavior and undefined agenda (Mosvick et al., 1987). Also, the spatial nature of decision conflicts among the stakeholders often needs to be resolved in real time. To address these issues users should be empowered with interactive simulation interfaces, which is informative and responsive to accommodate newer approach to effective participation in decision-making.

Rao and Jarvenpaa (1991) outlined the theoretical aspect of the effectiveness of the group decision support system with regards to the theories of communication, minority influence, and human information processing capabilities. Armstrong (1994) identified three stages of progress (strategizing, exploration, and convergence) to solve complex semi-structured problems of group decision-making. Dillenburg et al. (1992) put forward the idea of 'distributed cognition' and acknowledges that group decision-making can be supported by tools, which allow explicit representation and manipulation (visualization) of shared information. Gordon (2001) discusses an agent framework of "computational dialectics" of group decision support system as a mediator and regulator of the flow of messages between agents in distributed systems to facilitate the common goals.

DECISION MAKING AND SPATIAL DATA INTEROPERABILITY

As spatial data and services are increasingly being available, there is a growing demand for robust information services for explorative analysis, which can extract multiple services from different federated repositories of heterogeneous sources to support decision-making. The increasing demand of interoperability of heterogeneous systems is being realized as the data services grow exponentially. In general, the majority of services available online can be classified into two basic categories– i) information brokerage services and ii) *process* services for planning which basically work as facilitator by proving policy guidelines, list group support etc. These services are often uni-directional from server to client where the server still plays a central role in the information flow and system architecture. Serving spatial data from disparate sources and dissemination to target user was the vision of NSDI (National Spatial Data Infrastructure) expressed by the Mapping Science Committee (NRC, 1993). However, the vision of NSDI could not conceive of the enormous growth of Internet, which underemphasizes the importance of effective processes of dissemination to users (NRC,1999).

Standards and Protocols

A distributed spatial data warehouse framework for decision support needs to address various complex research issues ranging from technical, social and institutional aspects. There is a need to explore how the classical decision support framework fits with the emerging distributed autonomous services and whether these new developments can be coped with the arrangements of new standards, protocol, institutional regulations and so forth. The emerging emphasis on the decentralization of resources and services might need a novel approach to tailor decision models from disparate sources and customized them for user group. Very little research work has been on done on spatial interoperability aspect of distributed data brokering and spatial decision-making.

A large number of standards and protocols currently exist to support geospatial applications. From the operational point of view, the catalog interoperability of multiple repositories to exchange resources is the functional step to achieve compliance with different stakeholders. The metadata standard developed by the Federal Geographic Data Committee (FGDC) emphasizes the content standard of

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geospatial database rather than the database itself. At the object level, the Open GIS Consortium (OGC) is developing a number of specifications. The notable one is Abstract Specification, which includes the Essential Model and Abstract Model and forms the basis for development of (OGC) Implementation Specifications. However, semantic conversion from existing systems to OpenGIS is still very difficult (Camara, 1997). A higher level of semantic modeling is still required before the actual mapping of OpenGIS and existing system could take place (Yuan, 1997).

Other standard of relevance to distributed spatial data warehouse and decision support over the Internet include recent development of W3C's Semantic Web initiative to map the semantic variability of Web contents. The RDF recommendation (Lassila and Swick, 1999) provides a metadata description through a triple (resource, property, value) to describe resource content in web page. The reasoning and logical analysis RDF is supported by Defense Advanced Research Project Agency (DARPA)'s DAML family of Markup languages which offers a mechanism to integrate the modeling primitives of ontology language with enhanced RDF data model. In DSS, the distributed model management in the long run should conform to the framework of semantic web. This aspect is discussed in detail later.

Brokering Spatial Services for Decision Making

Understanding the semantics of spatial data is essential not only for exchanging data, but also necessary for the meaningful interaction of user community with respect decision support models. Spatial decision support system in a distributed environment needs access to multiple data sources and models to allow user to explore different decision scenario through explicit visualization. The issues of interoperability are often addressed by brokering services through a standard definition of 'interfaces' in a language neutral way. Broker based solutions such as COM or CORBA offers an Interface Definition Language (IDL) where different tiers of solution can be communicated regardless of language differences and processes. In Internet such services can be communicated through IIOP (Internet Inter-Orb Protocol). OpenGIS Simple Feature Specification outlines spatial data access for COM CORBA and SQL with respect to 'feature'- the basic unit of geospatial data and 'geometry'. The specification deals with data access rather than geoprocessing and does not provide for rendering on the server (Cuthbert, 1999). Client has to pull massive amount of data at his/her end and manage it locally. Such approaches assume client's explicit ability to manipulate server connection and invoke remote objects. Thus, frequent spatial processes such as spatial join between data from two different servers needs to be coordinated at the client's end. From the decision support point of view, having the data access at the client's end without robust geoprocessing capabilities amounts to little help. Also, user or decision maker's view on spatial features or geometry needs to be realized at a higher level of abstraction while at the same time maintaining the transparency of system processes. Such systems are yet to be realized within the decision support framework of geospatial interoperability of data and models.

Distributed Model Management

An essential feature of spatial decision support system is the integration of geographic data and geoprocessing function in a distributed environment. In the past many integration frameworks have been proposed (Chou and Ding, 1992; Nyerges, 1993; Abel et. al., 1994). However, these approaches do not support a model management system to support dynamic processing in different spatio-temporal scale. Additionally, these approaches include lower level simple data transfer to high-level complex coupling. As far as software reusability is concerned, in a distributed environment where there is little agreement on different components and modeling paradigm, lower level integration does not add much benefit when diverse models are to be communicated at higher level. Often GIS models are developed for specialized purpose tightly woven with data model without regards to system interoperability. Moreover, there is an inherent dichotomy of GIS model and environmental model. While the former focuses on representation of space-time relationship and spatial features, the latter are concerned with dynamic processes. Such space-process dichotomy determines the distinction in abstract models and languages used by GIS and models (Maidmet, 1996). To get around this problem, a unified conceptual model of the problem domain is essential prior to the system development. In a high performance distributed computing environment modularizing model component calls for an object-oriented approach which can accommodate flexible and iterative model processes incorporating prototyping, use of class libraries, reuse and re-engineering of other application code, and late configuration to changing requirements. Such object oriented modeling tools could be regarded as a generic decision model for problem of certain classes that can be customized through an instantiation process. The model formulation from the user point of view then becomes the simple process of choosing and applying a set of special purpose, domain oriented concept, which describes the problem domain. As far as the semantic contents of the models are concerned, a meta-model ontology would be necessary to describe and map the generic modules in a modeling language, which will allow creation of a globally accepted unique identifier over the Web. A possible candidate for this modeling language is Defense Advanced Research Project Agency (DARPA)'s DAML family of Markup languages. DAML based semantic translation can be used in the local process to invoke generic procedures. DAML could provide a declarative representation of Web service, model objects and user constraint in Web markup ontology and enable automated reasoning about declarative API (McIlraith, 2001). In a collaborative environment, multiple agents (both human or system automata) can specify different modeling parameters and constraints with different degree of preferences so that the resulting models conforms to the semantics of the model developers expressible in a universally accepted ontology. Such approach could help distributed model composition and management in a heterogeneous environment.

COLLABORATIVE SPATIAL DECISION SUPPORT SYSTEM: GEO-ELCA

GEO-ELCA is a collaborative spatial decision support system for exploratory land use change analysis services to support users to assess the non-point pollution impact of the land use changes. Land-use change has been identified as a major driving force of ecological changes. With the conversion of land use from one category to another there is an overall change of hydrological characteristics resulting from the changes of impervious area. Consequently there is an increase of volume and peak flow of possible increase in concentration of pollutants, which deteriorate the environment. The system allows an explorative model to evaluate the hydrological scenarios in response to the land use changes as a result of different stakeholders options. The Web interface allows user to select graphically a land use type and change it to a different category and then visualize the effect of different pollutants e.g., Total Nitrogen, Total Phosphorous, Total BOD, (Biological Oxygen Demand) etc.

GEO-ELCA Model

GEO-ELCA (Exploratory Land use Change Assessment) was developed following a three-tier application architecture where the map server receives requests and instantiate requested model through a web server. The user requests are received and managed by a middleware component or Web server, which administers requests and transmission of response between client and middleware tiers. The web server is developed with MapObjects components and Internet Map Server (IMS) (ESRI, 2001). MapObjects is a set of mapping components, which comprises ActiveX controls and automation objects specifically designed for mapping purpose, which could be used along with any ActiveX container. The client's response is received as http requests through an active-X enabled browser to support GIS functionality using JavaScript and ActiveX controls. The request is processed in an

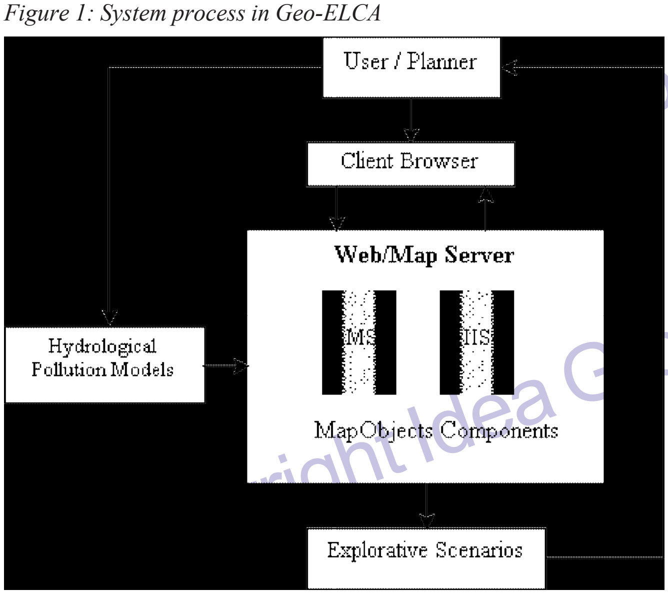
Application Programming Interface (API) and the result is then sent back to the Web browser in the form of images supported by the browser. The map server contains registered model components which are instantiated following a request from the client. GEO-ELCA implements the so-called "Simple Method"(Schueler, 1999) of estimating exports of various pollutants in runoff as a result of land use changes. At present, the model is tightly coupled within the map server. The integration of the simulation model and spatial database (in this case shape file) is achieved in response to user request to change a land use category. The model component is embedded in the MapObjects application following COM (Component Object Model) tools. The model inputs and outputs are communicated through the functionalities of MapObjects and ADO (ActiveX Data Objects) allowing connectivity to a remote data repository and passing the model parameters in the VB procedures and modules. IMS's built in WebLink ActiveX control communicate with Web server's dll component (ESRIMap.dll) to provide request and response heading to the map service application. These requests are then parsed to invoke the corresponding model component. The output of the processed results is then sent back to client's browser as a stream of HTML code through a specified MIME-Type http protocol. At the middleware level the application utilizes Microsoft's IIS 4.0 (Internet Information Server 4.0) to connect with the ODBC (Open Database Connectivity) to allow SQL query to the shape file and the tabular database.

As MapObjects IMS does not contain all the necessary tools for implementing cartographic rendering, several procedures were developed at the server level. These include typical mapping manipulation procedures such as: selecting and identifying a feature, zoom in/out, panning, visual query, rendering legend corresponding to feature types (for both continuous and unique data type), multiple theme overlay etc.

Additional features allows client to generates statistical report of pollution scenario, reclassification and visualization of pollutant distribution into different modes (e.g., binning pollution distribution into equal interval, in terms of standard deviations), interactive color rendering for continuous data set, generating tabular summaries of pollutant load (Kg/Yr) in terms of land use type.

In the context of multiple modeling options, the system is still being modified to accommodate multiple models within the existing architecture to allow user to different modeling parameters and domain classes to achieve generality and re-usability. An ontology reference is being designed in DAML where unique namespace for model objects are assigned. Following a user preference, the domain model is

Figure 1: System process in Geo-ELCA

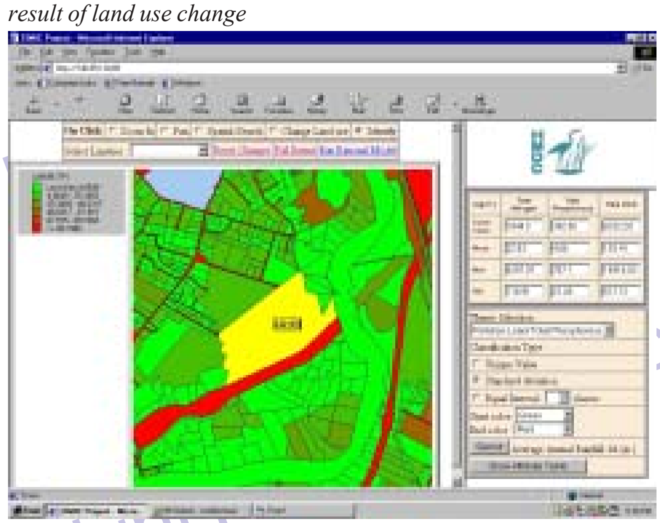


instantiated using inference engine to match with the model input and output parameters and invoke corresponding request to the server.

Exploring Decision Alternatives

One of the key features of GEO-ELCA is to provide user an exploratory tool to access appropriate environmental data set and model base and visualize the consequence of user decision. User can initiates a change in land use type by graphically selecting a polygon interactively of by processing a spatial query to search for a particular land use type. The server side application processes the request and makes necessary update in the database to reflect the corresponding changes of the pollutant coefficients. Every request to change in land use type results in recalculation of the mass export of pollutant and corresponding statistics. The processed result is sent back to the Web server and then to the client side. Geo-ELCA allows the various features of GIS services on the Web. The system allows dynamic selection of a feature type (i.e., polygon – land use class so that a user can change attribute items and identify a feature property. Following a change in land use type, a user can initiate the non-point pollution model to estimate the yearly pollution load and visualize the pollutant distribution in terms of different classification scheme with modified map legend.

Figure 2: Visualizing pollutant distribution (total phosphorous) as a result of land use change



The resulting pollution map can be visualized with multiple theme overlay. The system then generates reports of the tabular summaries of pollutant load (Kg/Yr) in terms of land use type which includes statistical estimate (min, max, standard Deviation of Pollution categories) of pollution content for a particular scenario. User can continue to change the land use type and inspect the results or revert to the original map plan. At its current stage of development the system does not offer any mediating algorithm to resolve multiple scenario or options of different users. Such algorithm might involve a group consensus building mechanism through or conflict resolution such as Analytic Hierarchic Process (AHP) to prioritize various options (Satty, 1989).

CONCLUSION

Explicit representation and manipulation of information from shared repositories is the key aspect of distributed spatial decision support systems, which needs to address geospatial data and model interoperability issues to allow seamless integration of modeling components. Currently there is no standard for re-use specification of existing spatial models, which could increase the effective application in the distributed decision support architecture. There is a strong need for a generic model formalism to link models to the domain specific knowledge (classes) through a decision support interface over the Web. A formal description of the component models will specify the *modus operandi* to allow the system to reason about the model in relation with the domain knowledge. The design of GEO-ELCA integrates GIS application model with component-based framework and serves complex analysis and simulation models to multiple stakeholders by providing a mechanism for exploratory decision scenario. Currently, the work is in progress to incorporate the domain ontology of non-point pollution model where the modeling components are expressed in DAML+OIL framework and an inference scheme is being prepared to composes these components to instantiate the mapping services within the Internet Map Server framework.

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