DESIGNING AN OIL SPILL INFORMATION MANAGEMENT SYSTEM

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ABSTRACT

This paper presents the architectural design of OSIMS, an Oil Spill Information Management System, which is an integrated information management tool that consists of an object-relational database management system, an adaptive decision suport sustem, an advanced visualization system (AVS) and a geographic information system (GIS). OSIMS will handle large and diverse databases of environmental, ecological, geographical, engineering, and regulatory information and will be used for risk analysis and contingency planning.

INTRODUCTION

Successful response to oil spills requires marshaling critical information in a real time (often for a sustained period of days-to-weeks) over a wide spectrum of topics, including surveillance data, environmental conditions, ecological factors, and countermeasure options (both from a technological and a legal perspective) (Meyers *et al. 1989*).

Response operations have many facets that are often fulfilled by a variety of agencies, all of which need access to critical information. A high degree of organization and preparation is required to support these information needs effectively (Jensen and Tebeau 1991).

Some of the information (e.g. geographical, ecological, legal, containment, and clean-up equipage, environmental sensor locations) can be acquired and organized in advance, typically through a Geographical Information System (GIS). Other types of information (e.g. winds, waves, and currents; vessel traffic; fishing fleet operations) must be dealt with in real-time. Tactical/operational decision-makers need to have this vast variety of data accessible, generally in a graphical display form. They also need to have comprehensive data pertaining to the oil spill event for the duration of the crisis and beyond. Obviously, a computer-based information management system is essential.

Similarly, there is a need for an organized information management system to support strategic activities, e.g. planning, training, and event reconstruction. The same basic information system should be able to support both tactical and strategic needs (Harrald *et al.* 1990).

This paper presents the architectural design of OSIMS, an Oil Spill Information Management System, which is an integrated information management tool based on an object-oriented database design that may provide comprehensive data pertaining to an oil spill event for the duration of a crisis.

In the following section, we present the database management system, that is developed to handle large and diverse databases of environmental, ecological, geographical, engineering, and regulatory information. GISs and Advanced Visualization techniques (AVS) to be used to integrate a variety of databases for risk analysis and contingency planning are presented afterwards. Finally, we present an adaptive decision support system which is designed to support oil-spill response decision makers with automated expert systems and tools to assist in strategic, tactical, and operational decision-making.

DATABASE MANAGEMENT SYSTEM

In preparation for an oil spill event scientists must deal with huge volumes and diverse sets of data. The proposed database will serve as an integrated data repository to many other types of subsystems. Decision support systems, visualization, and geographic information systems will access the data stored in the database. The database management system will provide transaction management for concurrent access, security control, and ad-hoc queries based on attributes and contents of pertinent datasets.

These data include geographic and environmental data, time sequenced observational data from cruises, buoys, shore stations, satellite images, and gridded multidimensional data from various simulation models. Regulatory information must also be stored and manipulated in a seemless manner. Most of these data have complex structures and do not fit well into a database model that is relational in nature.

Object-oriented database management systems provide the needed flexibility to support this diversity of complex data and their inherent behavior. But the low efficiencies and lack of easy-to-use ad-hoc query user interfaces of current object-oriented DBMSs make them difficult for real scientific applications. POSTGRES (Stonebacker and Kemnitz 1991, Olson 1993) is an extensible relational database management system with major object-oriented features: abstract data types, user defined types and procedures, attribute and procedure inheritance, and production rules.

Various new data types and operations have been defined for scientific data types encountered in OSIMS, such as image data types for AVHRR images, and two-dimensional or three-dimensional field data for large gridded datasets that represent the outputs of various simulation models.

MULTI – LEVEL STORAGE FOR OSIMS DATA

Because of the huge volumes of data in OSIMS, efficiency is a critical issue in the performance of the system as a whole. A large number of datasets consists of several megabytes and need to be stored and analyzed.

In addition, these datasets are rarely queryed for a particular point, but the scientists are concerned with the characteristics of the whole dataset, such as their images, their statistical attributes, etc. On the other hand the metadata of these large datasets and other management information will be queried very often. Storing all these data in one layer inevitably degrades the system performance.

Thus, we store the attributes of these large datasets and management information in relational tables, and the large datasets themselves in a unix file format that resort to the POSTGRES external large object interface. POSTGRES provides the different levels of data access, transaction management, and security control capabilities. The efficiency is achieved by having the DBMS access the metadata first. The large datasets are accessed only when needed.

DATA PRESENTATION AND ANALYSIS

The metadata of the large datasets and other management information can be presented to scientists in tabular format effectively, but large datasets are difficult to be understood or are even meaningless if presented in a tabular format. Large, time sequenced observational datasets and model outputs are meaningless if presented as raw data.

What we need is an integrated data browsing, visualization and analysis interface (Treinish 1992, Treinish 1993). In our system the metadata is browsed by relational tables, geographic and environmental data are presented by maps, large observational datasets and model output are presented by their images, geometries, or their animations.

Currently we are integrating POSTGRES, Advanced Visualization System (AVS) and the Geographic Information System ARC/INFO into a cooperating system for the OSIMS. Each of these provides a specific and individually complex functionalities (see Figure 1).

ARC/INFO provides a most powerful graphic presentation and spatial query capability for geographic data. By overlaying geographical data such as, the South Florida coast line maps, environmental and geological data (e.g. sensor locations, cleanup equipage, oil spill trajectories predictions) onto one map, the user can see the relation od critical features of the overall situation. Queries for relevant information, such as what amount of oil has been spilled in a specific place, can be directed from the icon of the visual representation.

POSTGRES provides the DBMS functionalities such as integrity management, concurrent multiuser access, independent user 'views' of centralized data, and access to the DBMS application tools such as forms and menus products. It also allows us to integrate with ARC/INFO , so that relational joins of the data in POSTGRES tables with geographic features in ARC/INFO can be made.

USING AVS AS A DATA ANALYSIS TOOL

We use the Advanced Visualization System (AVS) (AVS 1992) - a state-of-the-art visualization system with the capabilities of animation and distributed, concurrent computations - for data analysis in OSIMS.

More than 150 built in modules in AVS provide full image analysis such as image enhancement, edge detection, image transformation, and image display. Data analysis such as data sampling, data down-sizing, data filtering or data conversion and rendering such as graph viewering, or geometry viewing are also included. We have extended AVS with our own modules customized for OSIMS applications. The AVS visualization networks built on these modules provide the scientists with a unique vantage for insight into complex problems characterized by large data sets.

We have used AVS to visualize a variety of large datasets encountered in OSIMS, such as griddled 2-D fields of ocean current velocities from the ocean circulation model, time-sequenced observational data such as wind velocities, directions, air temperatures, sea surface temperatures from shore stations, and AVHRR satellite images. Currently, we are also using the AVS concurrent capability to animate the oil spill trajectory resulting from the output of the oil spill trajectory prediction model in real-time.

DBMS SUPPORT FOR SCIENTIFIC VISUALIZATIONS

Despite the virtues of visualization systems, they lack data management support. They give little built-in support for finding pertinent datasets based upon the attributes of the datasets other than providing a simple file browsing mechanism.

Oil spill researchers and responders need to collaborate in a multitask, multistage effort. This leads to the problem of multiple heterogeneous platforms as well as to problems of concurrent and timely access.

Based on the above observations, we recognized a need for a comprehensive system to support the management of scientific visualization data. The basic idea is to provide an integrated system which couples attributed-based dataset query with high performance visualizations. Even the most advanced file-based systems don't provide a solution to this problem. We are making extensions to POSTGRES to provide data management support for scientific data visualizations.

The second tactic in the subsystem is to have the AVS visualization network script, used to visualize the dataset, also stored in the database through the POSTGRES external large object interface. The pertinent large datasets are retrieved based upon the attributes of the dataset contents through a TCL/TK graphical user interface, the corresponding visualization is triggered automatically through the user interface. In this way, OSIMS researchers and decision makers don't need to invest a large effort to learn how to build AVS networks.

DSS FOR OIL SPILL COUNTERMEASURES

One can divide the oil spill decision-making process into three hierarchical levels: *strategic, tactical,* and *operational.* More specifically, the three levels can be defined as follows:

1. *Strategic Level,* where one wishes to determine the quantities, types and locations of equipment that should be stockpiled to respond to future oil spills. The estimates of the likelihood of oil spill frequency and the magnitude associated with the oil spills have to be used as inputs for making strategic decisions. The optimization models that tackle such decisions should take into account various parameters including spill frequency of occurrence, variability of spill volumes, different equipment types, fixed costs to open a facility, equipment acquisition, transportation, and operating costs, equipment efficiency and operability as a function of weather conditions, damage costs as functions of spill volumes and level of response. Stochastic modeling, along with mixed-integer programming techniques are applicable for this level of decision making.

2. *Tactical Level,* where one wishes to determine aggregate actions that should be taken to respond to a specific spill, such as what equipment should be dispatched on scene, how long that equipment should stay on scene, etc.. These actions are taken by a decision maker after the occurrence of the spill is made known. The decision maker has to address such post-spill issues as availability of equipment, performance degradation of the clean-up efforts with bad weather and uncertain movement of the oil spill. The trade-offs between the potentially high cost of oil spill damage and the high cost of clean-up operations has to be balanced. Tactical decision-making is two-fold; it consists of:

   1. *Optimal deployment of oil spill clean-up equipment:* An analytical framework can be developed to assist the decision maker to allocate optimally the available resources for cleaning up the specific spill after its occurrence is made known.

   2. *Contingency Planning:* When a spill occurs, an efficient spill contingency plan will help to limit the adverse effects of the spill. It should provide a quick and efficient response, should be economical, and should be flexible enough to adapt to the changes due to the availability and capacity of the personnel and equipment and due to the nature of the spill.

3. *Operational level,* where one examines in much more detail the act ions that must be taken on the scene, such as depoyment of booms, skimmers, dispersants, etc., to protect sensitive areas.

The DSS will also be used in the context of strategic decisions regarding location of oil spill response equipment, optimum equipment mix and effect on probable spills of alternative mixes and locations. A preliminary literature survey (Iakovou *et al.* 1994) has shown that the problem has not been fully addressed and the characteristics of tropical environments are not well understood.

Discrete optimization tools can be used to tackle this level of decision making. However, because of the computational complexity of the problem and the required storage space exact algorithms should not be employed. Rather, approximate algorithms that give near-optimal solutions can be derived.

KNOWLEDGE – BASED DSS

The Decision Support System (DSS) will serve a central role in all aspects of tactical operations. Our main concern is to aid, not replace the agent in the field, but we wish to entrain as much expertise as possible within the system. Some basic goals include automatically logging event data, providing a portable package of relevant reference material, simple inference, operating with uncertain and incomplete data and explanation of reasoning. Our single most critical concern is to coordinate the quantities of regulatory and situational data, decision procedures and method knowledge on a per task basis so that the individual user is supported and not overwhelmed by the available information. The crisis nature of oil spill management exacerbates the problem of information overload.

Knowledge-based systems are a perspicuous and direct way to represent heuristic plans of the sort found in spill response documents (Goul *et al.* 1992, Steiner *et al.* 1991, Decker 1987). They are effective in environments where there is no closed solution to the problem, but expertise does exist. A knowledge based decision support system (KBDSS) can extend system capabilities to deal with the formation, analysis and critique of plans. Such a system can suggest, rank and explore options based on preference criteria; by choosing rules that fit the situation, by applying salience measures, or by invoking and using simulation data. We intend to wrap traditional methods of DSS, GIS, database systems and interface shells, in an intelligent information system which can connect these in a more higher level manner and provide a number of further services.

A first step in constructing the KBDSS is to implement rules which contain the information typically found in the decision matrices common to response plans. A rule based system invokes rules in a chaining fashion, facts about the current situation used to infer to arrive at further facts and eventually to reach conclusions. The checklists common to response plans can be included in a rule based system as procedural knowledge, or in a less lock-step mode, as related trains of rules. This is fairly standard technology from expert systems. Current efforts are building and testing the elementary rule bases and inference techniques.

The desire to maximize use of available resources, of database, GIS and model information has led us to propose the migration to a distributed expert system of heterogeneous elements. These are sometimes called federative expert systems. Such a system should allow us to take advantage of the great amount of expertise already entrained in traditional systems, maximizing not only the response effort, but the research effort as whole.

Correct, timely and focused information is critical to effective spill response. High connectivity and communication is a double-double edged sword entailing that we both reach out to get information available and conversely that we limit the inflow of information to avoid operator overloads. Only a few simple interactions between externally created information systems will be included.

A number of benefits can be secured by creating a distributed network of independent. intelligent nodes. Where several agents could effect a task, bargaining, on whatever criteria, could be effected. Conversely, tasks delegated by a central command can arbitrated based on local knowledge. It is critical that our efforts at this point already take in account these long term goals. Three goals guide us: 1) extending the use of heterogeneous elements information systems 2) establishing, controlling and deciphering communication 3) accurately coordinating forces.

In the short- to mid-term we will create knowledge-based interface agents for those nodes in the system which do not support knowledge based reasoning. For the excess overhead, we should, be able to tap the vast amount of data collection, simulation modeling and procedural knowledge already in place. In the short-term we are focusing on retrieving/generating information on demand. In this scenario, a non-intelligent system will be driven by requests put to an intelligent interface unit (IIU). The IIU is a knowledge-based shell tailored to activate and communicate the results of the local resource, driven on command by planning agents. In the mid-term we need to expand to interaction between elements, say by bargaining simulation exactness or granularity against result deadlines. Figure 2 shows the interactions between agents and databases.

CONCLUSIONS

A regional prototype Oil Spill Information Management System has been presented. The system includes objected oriented databases, visualization systems, geographic information systems, expert decision support tools, optimization tools, and modeling and simulation tools.

Our future work will concentrate on a distributed architecture that will allow multiple heterogeneous systems to cooperate in an overall task. Since spill response actions are to be carried out with all deliberate speed, in the milieu of independent agents it becomes critical that the individual elements of the system be able to provide suggestions in real (event) time; even in the absence of complete, totally reliable situation knowledge. We are also interested in extending the essential capability of the inference mechanism to deal with time critical information that is missing, imperfect or which may possibly to be superseded. The requirement is to provide a reasonable "any-time" deduction mechanism so that it all but the most extreme cases some reasonable action can be put forward.

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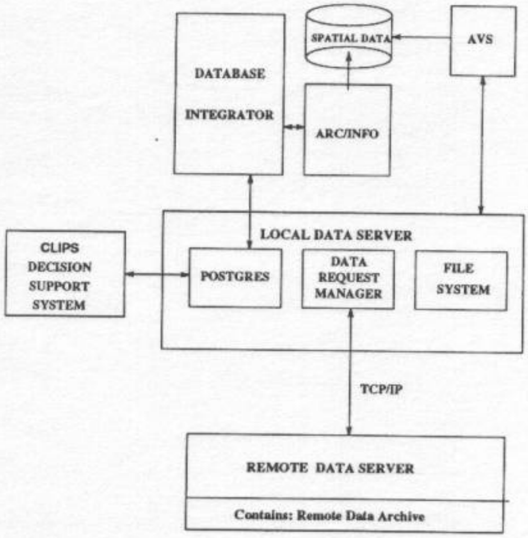

Figure 1 A PROTOTYPE FOR INTEGRATED OIL SPILL INFORMATION MANAGEMENT SYSTEM

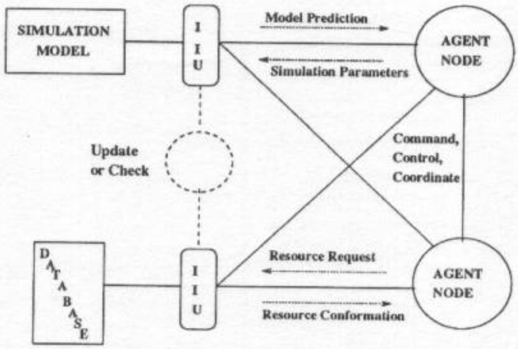

Figure 2 A SYSTEM OF INDEPENDENT AGENTS WITH INTELLIGENT INTERFACE UNITS RESPONSIBLE FOR KNOWLEDGE BASED COMMUNICATION