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Enhancing Situation Awareness in real-time Geospatial Visualization

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ABSTRACT

Today's hardware and software infrastructure enables large-scale visualization of (near) real-time data in a geospatial context, which is attractive in a variety of application areas ranging from military applications to disaster management and incident response. The drawback on the other hand is that combined visualizations might lead to an overload of human processing capacity, for instance if multiple dynamic aspects must be observed in parallel. The objective for our research is to develop a solution which enhances the situation awareness of the user by identifying the appropriate means of visualizing information based on the user's task and a given situation. In this paper, we propose an approach and associated system architecture how this objective can be reached. The primary ingredient of our approach is the combination of a GIS system and logic-based ontology representation and reasoning system.

Keywords (Required)

GIS, Situation Awareness, Decision support, Visualization

INTRODUCTION

The increased computing capabilities that we experience as a result of Moore's Law, enables more complex applications with modular designs that would have been infeasible only a few years ago. Geographic information systems ("GIS") profit greatly from that and allow to model and analyze spatial datasets of increasing complexity. Two developments further enhance the capabilities of future GIS. First, graphics adapters also become more powerful and cost-effective - the rendering capability available in mainstream graphics adapters was once an exclusive domain of costly graphics workstations. Second, an increasing degree of network connectivity, particular wireless connectivity, makes real-time feeds of sensor data feasible.

Taken together, these developments will enable large-scale visualization of (near) real-time data in a geospatial context, which is attractive in a variety of application areas ranging from military applications to disaster management and incident response. Recent examples where such a system would have been beneficial include the Tsunami that hit at least nine Asian countries and caused deaths in the ten thousands. The media reported on difficulties to organize the help and to make the funds raised world wide available where they were needed most. A geospatial context would provide intuitive access and navigation of the information space that must be processed to organize a timely, efficient, and effective response.

However, in order to utilize such information systems to their fullest potential, numerous hurdles have to be overcome. One such hurdle is the limited cognitive capability of their human operators. Typically, the capacity of humans' short-term memory (or working memory) is limited, which means that the context of a task can be comprised only of a few items. Additionally, humans have difficulties to attend to multiple processes simultaneously. Task switching takes considerable time and quickly renders one's work inefficient.

There is a clear need for information systems which supports users depending on their task context in an intelligent way. Towards intelligent support of human operators of large-scale geospatial visualization systems, we explore an approach that focuses on *decision centered visualization* (“DCV”). On a high level, decision centered visualization is concerned with two aspects of visualization:

1. Which of potentially many items must be visualized in a given situation?
2. How items are visualized best with regard to a user’s goals?

The first question leads to an information *item* selection strategy whereas the second question leads to strategies of *attribute* selection. At the same time, numerous practical constraints have to be met, such as selection of appropriate standards and tools such that diverse information sources can be integrated and deployment of the information system is easy. In this paper, we propose an approach and associated system architecture how these design objectives can be reached. The primary ingredient of our approach is the combination of a GIS system and logic-based ontology representation and reasoning system.

The remainder of the paper is structured as follows: first we outline cognitive considerations and related work. The detailed description of our approach chosen is divided in an outline of the system requirements and thorough presentation of the architectural approach chosen. The crucial parts “knowledge representation” and “utilization of COTS GIS” are discussed in further detail. A hypothetical example is used to explain the application of our approach.

Cognitive Background considerations

The limitations of human's cognitive capacities are a challenge that must be overcome when designing large scale and real-time systems. The short term memory (STM) of humans was believed to be limited to seven plus minus two symbols, based on the seminal work of (Miller 1956). Recently, Vogel and Machizawa found neurophysiological evidence that the capacity of the visual working memory is closer to three to four symbols (Vogel and Machizawa 2004). Principally, the constraints of the STM can be alleviated by rehearsal (the process by which items are transferred from STM to long term memory). However, a stream of new information items that must be processed, as is the case in an analyst's work, impedes human's ability to rehearse and thus to remember (Peterson and Peterson 1959).

Objective

In our approach the amount of information that is presented to an analyst per time unit is tightly controlled. That, of course, requires that the presented information is relevant to the analyst's current work task. The decision, which information is presented and which is not, is performed by means of regional, domain, and task knowledge. That information is merged with received real-time data. By using information on current tasks and a concise presentation of task-relevant information, our approach aims at avoiding information overload. Automatic processes decide what needs to be displayed depending on the user's task and situation, and finally choose an appropriate information presentation based on the current interaction mode and the priority of the information. Nowadays GIS platforms are often following a query-answer paradigm. They typically do not react on dynamic data changes, if a user does not query against a corresponding database explicitly (Kohlhammer, Schulz 2005)

Technical objective of this research is the development of an open and flexible architecture for the described approach which includes especially the linking of knowledge based information representation and processing with GIS specific objects. In that regard, we outline requirements for such a system and describe an architecture which provides a solution for the stated requirements.

Related work

(Kohlhammer and Zeltzer 2003) investigated decision centered visualization and concluded that even though there had been a significant amount of work in the human factors community aimed at developing models of situation awareness, especially in time-critical domains such as aviation (Klein and Zsombok 1994) or with regard to intelligent user interfaces (Brusilovsky and Cooper 2002; Eisenstein and Rich 2002; Kerpedjiev, Carenini, Roth, and Moore 1997). However, none of this work has specifically addressed the requirements of visualization systems in time- and safety-critical domains.

GIS related applications fields which process real time data are currently addressed by various vendors providing specialized supporting software packages such as ESRI Tracking server, IntelliWhere Track Force or MapInfo miAware. A typical application scenario of these systems is among others fleet management.

Our research focuses on identifying the appropriate means of visualizing information based on the user’s task and a given situation. This requires modeling of applications’ semantic as well as the user’s task. Various approaches are possible for

modeling this knowledge. (Strang and Linnhoff-Popien 2004) investigated various methods for context modeling. Even though the application focus was ubiquitous computing applications, the findings of their research can be mapped to our research and development focus. In their comparison they included among others Markup Scheme Models, Graphical Models, Object oriented Models, Logical based Models and Ontology based models. They concluded that an ontology based modeling provides the most promising assets.

DECISION CENTERED VISUALIZATION IN GEOSPATIAL ENVIRONMENTS (DCVGE)

In this chapter our realization approach is described. First the requirements for the system are outlined. Then our proposed architecture is illustrated. Finally important aspects of the approach are discussed in further detail.

Requirements

The development of a system for decision centered visualization in geospatial environments addresses a fairly new field. Although there have been investigations and developments in various connecting areas as discussed above, there was only limited research in this dedicated domain. Under these circumstances a most promising approach is to develop requirements for such an application. Based on these requirements, design decisions are to be made consequently proven by a prototypical development. Based on considerations for various application scenarios we derived the following high level requirements for the application:

- **Modeling of the application's semantics and the user's task:** A flexible mechanism needs to be found which supports the modeling of such aspects. Moreover it is important that the implementation does not rely on the actual content of a specific application. Rather, the model should be exchangeable easily. Besides the modeling of the data, an inference mechanism for reasoning on that model is of equal importance.
- **Utilization of COTS GIS:** Dealing with spatial and geographical datasets, is the domain of geographic information systems (GIS). Instead of reinventing existing technology when developing the necessary functionality for storing, managing and visualizing the spatial datasets, the solution should be designed such that it utilizes established mature technology.
- **Web based access:** The question how the user accesses the system has significant implications for the system architecture (i.e., whether the user utilizes a desktop system or the access is provided through a web browser). The main advantages of the desktop solution are optimal utilization of available HW and software resources, which leads to a high overall performance. The Web based access on the other hand enables users to work with the system without prior installation. This is an important consideration if the size of the user group working with the system should be scalable to Intranet or even Internet dimensions. In order to obtain maximal flexibility in this regard, the system should be accessible through a Web interface.

In addition to the high level requirement further technical constraints can be identified. The data handling of the application has to support static pre-computed spatial and environmental information as well as the processing of dynamic real time input from various input sources such as sensors and other online sources. A sophisticated approach needs to be in place which combines all these information and maps it to appropriate visualization descriptions. The visualization part needs to provide the means to allow the decision modules to perform the proper presentation by manipulating the visibility and appearance parameter of the graphical objects within the GIS environment.

Architecture

Based on the requirements stated above, we propose the architecture as shown in Figure 1. The architecture consists of three areas:

- The "data source" part shows of the various input sources for the system. The input data consists of the domain knowledge and the task knowledge, the dynamic real time data and the geospatial data.
- The "decision control" part of the picture describes the decision centered aspects of the application including the event handling, administration the domain knowledge and management of the visual appearance according to the findings of the knowledge management.
- The "geospatial visualization" part describes the GIS component, which is responsible for handling and managing the spatial data, maps and visual attributes. This component builds also the interface to the user, which accesses the system over the internet as shown.

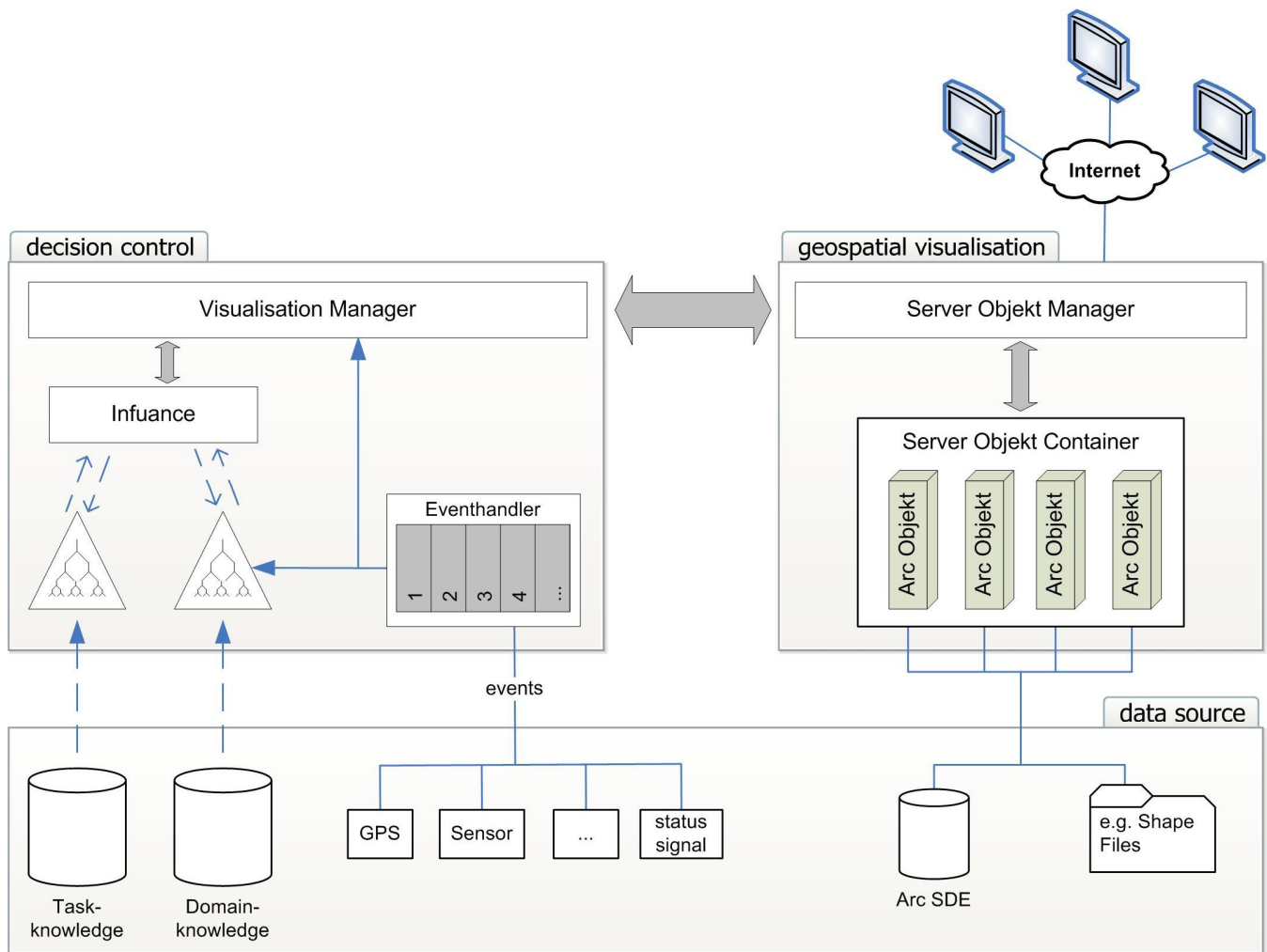


Figure 1 Architecture of DCVGE

In the following two important aspects are described in more detail, first the methodology chosen for the knowledge modeling and the approach for handling the geospatial data.

Knowledge Modeling

The initial question is what knowledge representation technology is appropriate for the tasks at hand. Ontologies are used to structure knowledge into a hierarchical system that supports generalization as well as specialization and association (see e.g., Strang and Linnhoff-Popien (2004)). Ontological knowledge representations are our mechanism of choice as well, not least because considerable support for building ontology-based systems is available through the efforts invested in building the Semantic Web (SW). Technologies that were developed in the context of the Semantic Web are the Resource Description Framework (RDF), the DAML/OIL markup language and the OWL Web Ontology Language. These technologies provide the necessary level of functionality and maturity and can be used for the modeling of the knowledge for our application even though they were initially developed for SW. (Kohlhammer and Zeltzer 2003) achieved good results by applying DAML/OIL for knowledge modeling in the system they developed. The most recent technology with this regard is OWL, which models knowledge in an object-oriented approach: the structure of a domain is described in terms of classes and properties. OWL also provides the means for reasoning. (Wang, Zhang, Gu and Pung 2004) investigated OWL for reasoning and they concluded the general feasibility of the OWL approach. However they noted that special attention must be paid when applying OWL reasoning to time critical applications. The size of the rule set is a concern to the scalability of the approach.

A state of the art development environment is provided by Jena2 (Jena2 Semantic Web Toolkit) which supports OWL and also provides different inference engines for reasoning.

Utilization of COTS GIS

Nowadays several GIS vendors do not only provide closed solutions for GIS operators but also libraries and frameworks which enable the development of tailored, specialized applications with a GIS component. One example is the development environment provided by the ArcGIS 9 suite from ESRI (The vendor ESRI was chosen since it is the marked leader in the GIS domain). ESRI provides different tools for building own applications based on so called ArcObjects which are an integrated collection of cross-platform GIS software components. Both tools ArcGIS Engine and ArcGIS Server provide potential for developing tailored GIS applications. The ArcGIS Engine, however, focuses on desktop applications. The ArcGIS Server provides capabilities for developing server applications, including web based applications. According to the requirements stated above, that the access should be provided over the browser, a server based solution will be required. Thus ArcGIS Server is the technology selected for our development.

The ArcObjects contain data which was originally converted from shape files or other typical ESRI geospatial datasets. The Sever Object Manger (SOM) has the ability to control the visualization of the ArcObjects. The SOM is therefore the interface to the visualization manager.

Application example

As an application example the following scenario in the domain of homeland security might be considered. Biomedical information would be monitored on different locations of the country and submitted to a central location. The STATPack (Fruhling, Tyser et al. 2005) project describes such a scenario for the state of Nebraska. The project successfully implemented an inspection and communication infrastructure between rural laboratories and the Nebraska Public Health Laboratory. On a central location all the information from theoretically all clinical health laboratories is present. The connection of such an environment with GIS provides the analyst the geospatial relations of upcoming incidents. The conclusion, which can be drawn from such visualization are significant better than from purely table based information. This, however, can be considered as state of the art. For our approach we make the following assumptions:

1. A domain-specific ontology models the knowledge on the interplay and relations between biological agents such as viruses or bacteria. This information can also be used to tie together diverse biomedical databases.
2. We particularly assume that information e.g., on incubation time, spreading rate, etc. is available. Such information is necessary to evaluate models and to predict how contagious an agent would be in a population with given density and mobility.
3. The GIS system will be used as a tool to support models that predict the spreading of an agent, as well as a tool to visualize critical areas and points of the transportation infrastructure that must be controlled to limit the rate at which the agent can spread.

GIS systems can provide critical information that is required for accurate prediction and response in incident and emergency response. For instance, a GIS system can deliver:

1. Population density (higher density increases the likelihood that an agent spreads through human contact)
2. Demographics (populations at different ages will show different infection rates and also have a different level of mobility and social contacts)
3. Primary traffic routes (which are more likely being used, provide faster transportation, and are thus critical to contain the spreading of an agent)
4. Transportation hubs such as airports (via a hub, an agent can potentially jump to disparate locations at great distance which quickly renders any attempt to contain the spreading futile)

In addition to that, GIS systems may be augmented with additional layer information that is perhaps more rarely found currently, such as information on average traffic flows through junctions, roads, bridges, and other infrastructure elements. Such information may enable more accurate modeling of the rate at which an agent be spread.

As time progresses, an increasing amount of complex information must be conveyed to the response forces and analysts, and false or delayed decisions can thwart any attempt to contain the outbreak of an agent easily. This means that any means by which the system visualizes the state of the situation must be highly accurate and effective. For illustration, we give an

example map in Figure 2. The map shows primary traffic roads in an area as well as major transportation gateways in the vicinity of the hypothetical event that can act as a springboard for an agent. The presented sample map is generated by human queries to a GIS dataset. The goal of our approach, of course, is to generate this view automatically.

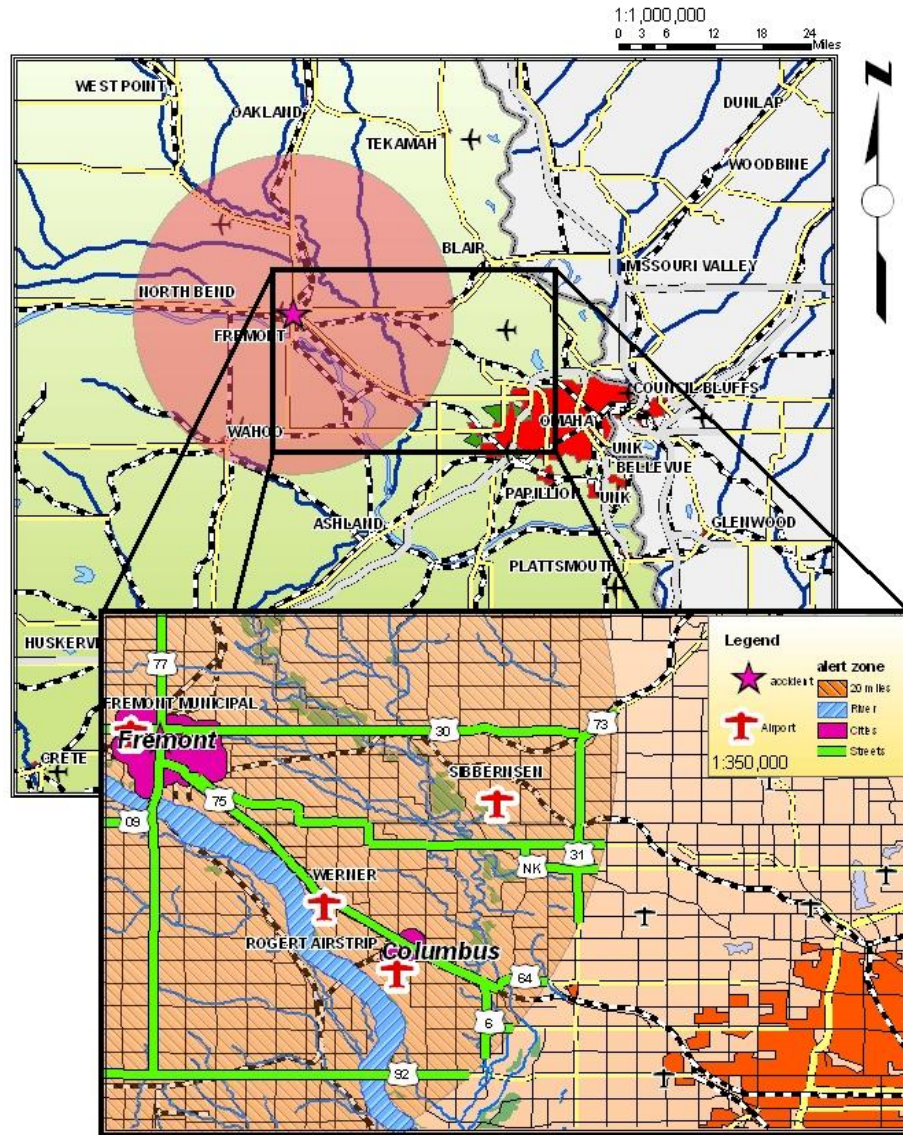


Figure 2 The map shows a local region and emphasizes the mayor traffic roads as well as major transportation within the peripheral of the city of Fremont within an area of 20 miles.

Data processing within DCVGE

In this subchapter we describe data processing for new incoming events in order to demonstrate how the modules of the architecture interoperate.

As an example we consider the fictive application scenario described above. The system visualizes map based an environment containing cities, streets, transport gateways and location of reporting laboratories. When a new incident is reported, the event is caught by the event handler which updates the knowledge base and triggers the visualization manger. The visualization manager triggers inference process. The result of this process will be interpreted by the visualization manager who will trigger the change of visualization at the Server Object Manager. The request from the visualization manager could demand the emphasizing of city where the incident happened, the street exceeding a certain traffic volume and the traffic gateway within the certain buffer around the incident origin. In case gateways are includes in the buffer region, visual hints to the connected gateways might be given as well. Examples for this visual emphasizing are among others, change or alteration of the objects size, color and transparency. Other means for tracking the user's attention are e.g. the appearance of an alarm window or the change of the viewing parameters in order to bring the current issue to the focus of the user.

RESULTS

The results of the research are the sound standing architecture and the overall concept. The next step of our research will be the implementation of the architecture and the concept. Moreover, for parts of the decision control component the implementation will make use of the experience a prototype in a non GIS environment from (Kohlhammer and Zeltzer 2003). For the implementation, however, we face additional challenges which we have to overcome for instance: the time for the reasoning cycle. As pointed our by (Wang, Zhang et. al. 2004) the reasoning depends highly on the complexity of the dataset as well as on the complexity of the rule set. Tests will be necessary about the limitation of these parameters when addressing real time applications.

CONCLUSION

The challenge for our research was to develop a solution which enhances the situation awareness of the user by determining which of potential items must be visualized in a given situation and how the items are visualized best with regard to a user's goals? Three main requirements were developed; first an appropriate knowledge managements methodology, second the utilization of COTS GIS-software for management and visualization of the spatial data and third the access to the system over the internet. We developed an architecture fulfilling these requirements. Our approach uses ontology's as the basis for knowledge management and reasoning. The GIS functionality is provided by ESRI ArcObjects which enable the web based access solution be utilizing the ArcServer technology.

The paper described the current status of our ongoing research. Following the concept and the architecture the next step leads to the development of a proof of concept prototype and its application. Beside the technical challenges, we will have to pay special attention questions regarding usability and users perception of the visualization techniques.

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