Decision-centred Visualisation in Civil Crisis Management

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Summary

This paper describes an ongoing research work on developing methods for effective visualisation support for situation analysis, decision making, and communication in the course of disaster management. The major goals are to reduce the information load of the analyst, decision maker, or information recipient without omission of anything important and to ensure quick and accurate comprehending of the information. The work embraces the issues of selection of the relevant information and defining the appropriate level of detail, data preparation (aggregation and other transformations), and selection of the appropriate methods for visual representation depending on the user's tasks or communication goals, recipient's profile, and the target presentation medium. A practical outcome from the research will be a knowledge base that can be used to support analysis, decision making, and information communication in emergency situations. A great part of the knowledge, specifically, knowledge on data transformation and representation, is generic and can be used for different applications.

1. Introduction

This paper describes a research work carried on within the integrated EU-funded project OASIS (IST-2003-004677, coordinated by EADS France, started in September 2004, duration 48 months; see http://www.oasis-fp6.org/). The project as a whole aims at defining a generic crisis management system to support the response and rescue operations in case of large-scale disasters. The research presented here focuses on the use of intelligent visualisation for supporting the crisis management personnel in the analysis of the situation, finding appropriate ways to solve problems, making well-grounded decisions, as well as for informing and instructing the crews, partner organisations, and population.

The objective of intelligent visualisation may be formulated as "give everybody the right in-formation at the right time and in the right way". This statement involves two aspects:

1. A person or organisation (further referred to as "actor") should be timely supplied with the information that is necessary for the adequate behaviour in the current situation or fulfilling this actor's tasks.

2. The information should be presented in a way promoting its rapid perception, proper understanding, and effective use.

The first aspect refers to the problem of the selection of the relevant information, depending on the situation and the needs, goals, and characteristics of the actor. The second part refers to the problem of effective preparation, organisation, and representation of the information. This, again, depends on the goals and characteristics of the intended recipient and should take into account the specific constraints of emergency situations, in particular, the time pressure and stress factor.

The general requirements to intelligent visualisation include:

- Reduce the information load on the recipient: not only irrelevant information should be excluded but also the relevant information should be adequately aggregated and generalised leaving out unnecessary details.

- Choose representation techniques and design the display so as to ensure quick and accurate recognition of the meaning of the information conveyed.

- Take into account the characteristics of the medium used for viewing the presentation.

Intelligent visualisation supposes that both the selection of the relevant information and the subsequent processing, organisation, and representation of the selected information are automated. This is done by applying the knowledge base technology, i.e. incorporating expert knowledge in the visualisation software.

A similarity can be noted between the definition of intelligent visualisation presented above and the notion of decision-centred visualisation (Kohlhammer and Zeltzer 2004), which means the usage of problem-oriented domain knowledge for intelligent data search, processing, analysis, and visualisation in time-critical applications. However, this does not include knowledge-based design of visual displays for communication purposes such as instructing specific addressees how to act or alerting to a danger. Our view of intelligent visualisation embraces the use of visual displays for data analysis, decision support, and information communication.

2. Two modes of using intelligent visualisation

The intelligent visualisation is used for two different purposes:

o Build an interactive display to support the work of an analyst, planner, or decision maker.

o Build an information presentation for sending to a specific recipient.

The first type of use supposes that the information is presented directly to the user of the system. The display is shown on the screen of the same computer where the system runs and remains linked to the system, i.e. may be further controlled and updated by the system when needed.

The second type of use supposes that the presentation is intended for another person or group of people. The display must be standalone so that the addressee could view it independently of the system and not necessarily on a high-end computer screen. Thus, performers on site may be informed and instructed by means of hand-held or head-mounted devices but also on paper (e.g. by fax). People in the danger zone can be alarmed, warned, and instructed through their mobile phones and electronic information boards while information kiosks may provide additional information when appropriate. General public (observers) is usually informed by means of TV and newspapers. Each type of media imposes its specific constraints on how information can be presented and further dealt with. The intelligent visualisation support system must take these constraints into proper account.

3. The knowledge for intelligent visualisation

The following types of expert knowledge are needed for the intelligent visualisation:

- Emergency management domain ontology: a system of general notions relevant to the domain of emergency management and the relations between those notions. This includes
  - Various types of events such as fire, flood, or chemical contamination, their elements (agents) such as flame, heat, water, or hazardous substances, and the effects that may be produced by these agents such as ignition, detonation, destruction, or contamination;
  - Types of objects entailing latent dangers and the agents that may activate those dangers. For example, petrol facilities are hazardous in case of ignition while an electric transformer station is a source of risk in case of leakage of a flammable gas;
  - Various groups of population that may require help, their special needs, and types of places where these population groups may be present, such as schools, hospitals, or shopping centres;
  - Generic tasks that are often involved in emergency management, such as evacuation of people, animals, and valuable objects from the danger zone;
  - Types of resources and infrastructure that may be needed for managing emergency situations, including people, teams, and organisations (e.g. a fire brigade or a bus company), transportation means, roads, sources of power, fuel, and water, and so on.

- Generic actors (roles) involved in an emergency situation and their typical information needs. The following generic roles are considered:
  - Analyst: a person (typically in the situation control room) that needs to understand the current situation and its development, identify problems, and find proper ways of solving the problems.
  - Decision maker: a person who chooses a specific way of solving a problem from the possible variants defined by the analyst (which may be, in particular, the same person as the decision maker).

- Planner: a person who builds a plan for realising a chosen way of solving a problem or achieving a specific goal, assigns tasks to performers and allocates available resources to the tasks. Again, this may be the same person as the analyst and/or decision maker.
- Performer: a person, group, or organisation fulfilling a particular task or sequence of tasks. A performer may need to make various tactical decisions depending on the specifics of the situation and its changes.
- Sufferer: a person, group, or organisation that is exposed or may be exposed to some of the danger factors of the emergency situation.
- Observer: a person or organisation that is not directly involved in the emergency situation but is interested in receiving information about it. This includes, in particular, the mass media, which broadcast information about the situation to the general population.

- Techniques and methods to manipulate, organise, and present various types of data, which include:
  - Methods for data aggregation, smoothing, interpolation, transformation from absolute values to relative, change computation, etc.
  - Principles of choosing display types and graphical primitives according to data characteristics.
  - Principles of representing data according to the tasks they are supposed to be used for.
  - Methods for combining several displays providing complementary information.
  - Methods for controlling the level of detail and the visual prominence of information depending to the degree of relevance.

The knowledge on data manipulation and representation is independent of the emergency management domain unlike the former two categories of knowledge, which are domain-specific. It is therefore reasonable to separate the domain-independent and domain-specific knowledge. This approach allows the visualisation knowledge to be reused for other applications.

The entire intelligent visualisation system can be viewed as consisting of two cooperating expert subsystems, which may be called "emergency management expert" and "visualisation expert". The emergency management expert selects the necessary information depending on the needs of the intended recipient determined by recipient's role and the current status of the situation. Then the visualisation expert finds appropriate methods for transformation and presentation of the selected information.

A critical issue in building any expert system is the acquisition of the necessary knowledge. The success or failure of the endeavour depends chiefly on the quality and comprehensiveness of the knowledge that can be collected and adequately represented. To solve this challenging problem, we take an incremental approach. We start with a few selected types of emergency events and their agents, a subset of actors, and a limited set of data types dealt with. We also do not try to build at once a full knowledge base on data manipulation and visualisation but choose a subset of methods to address. In case of success of the pilot prototype, it will be gradually extended and elaborated.

As the source of domain-specific knowledge, we use the literature on crisis management (e.g. Rosenthal et al. 1989, Rosenthal and Pijnenburg 1991) and available reports about real incidents. Much information concerning the management of real disasters can be found in the news reports from various news agencies available, in particular, on the Web. Thus, using the Web, we have compiled a rather detailed description of the course and management of the flood in Czech and Germany in August 2002.

The domain-independent knowledge on data preparation and visualisation comes from the extensive literature on information visualisation, geographic visualisation, data analysis, and graphics design. We have recently summarised the current state-of-the-art in these areas with the focus on techniques and tools supporting data exploration and analysis (Andrienko and Andrienko 2006). Additionally to this, we need the knowledge concerning effective information presentation according to the intended communication goals. The relevant literature is rather abundant and includes exposition of general principles (e.g. Tufte 1997), descriptions of practical approaches to automated presentation design (e.g. Casner 1991), and reviews of techniques suitable for specific purposes such as increasing the visual prominence of the most relevant information (e.g. Reichenbacher 2005). Our orientation to various types of output media necessitates the use of knowledge concerning the possible ways of presenting information on these media. In particular, we can use the recent research results concerning information visualisation on mobile devices (e.g. Gartner and Uhlirz 2001).

4. Putting the knowledge in operation

The organisation and functioning of the intelligent visualisation system can be schematically represented as is shown in Figure 1.

According to the approach adopted, the emergency management expert uses the domain-specific knowledge in order to find and retrieve the addressee-relevant information and to supply it with meta-information that allows the visualisation expert to interpret, process, and present this information adequately. The meta-information includes the following items:

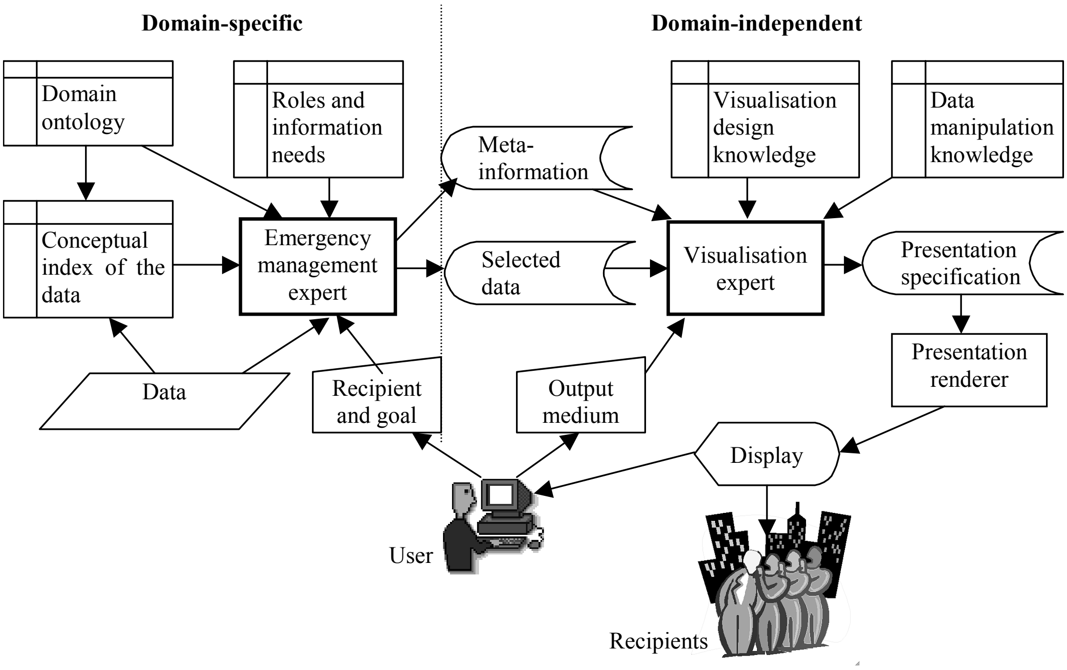

Figure 1: A schematic representation of the structure and functioning of the intelligent visualisation system for emergency management.

- Type of the entities the information refers to: movable or unmovable objects, places, processes, actions, or relations.

- Structure of the data and types of the components they consist of: spatial, temporal, numeric, ordinal, or categorical.

- Quality and certainty of the information: does the information result from actual measurements or observations or from prediction or estimation? What is its degree of accuracy or certainty?

- The goal of providing the information to the addressee:
    - alert, attract attention to something unexpected like an impending threat;
    - inform: what, where, when happens and how evolves;
    - suggest, e.g. some action to take or additional information to consider;
    - enable: analysis, reasoning, decision making, or action planning;
    - instruct: what, where, when, how to do or to avoid;
    - explain or justify, e.g. a proposed solution or a decision made.

- Degree of relevance to the goal: information of primary importance or supporting information (e.g. orientation clues).

- Degree of novelty to the addressee: new or known.

- Criticality, i.e. whether an information item requires immediate attention of the addressee.
- The expected level of addressee's knowledge concerning the topic of the information and the geographical area the information refers to.

The meta-information concerning the character, structure, and properties of the information comes from the indexing of the information items in terms of the domain ontology. The emergency management expert must specify this meta-information in a domain-independent manner so that the visualisation expert could use it without having any domain knowledge.

In the use cases when the intelligent system generates an interactive display directly for its user to support situation analysis or decision making, the goal of providing information is typically clear from the current context of the system use as well as the information needs of the user. In the cases when the user wants to send some information to a different actor, the user is expected to specify the addressee's role and geographical location and the goal for which the information will be used. On this basis, the emergency management expert can estimate the degree of relevance, novelty, and criticality of each information item for the recipient. For this purpose, it uses the domain knowledge concerning the actors (roles) and their typical information needs. The same knowledge allows the expert to estimate the probable level of addressee's thematic and geographic knowledge. Thus, an analyst may be qualified as an expert in emergency management issues but the level of knowledge concerning the area of the incident may be low. In opposite, the local population to be alerted may know the area quite well but be unaware of the character of the particular threat and the possible consequences.

Since the information is selected and supplied with the meta-information, the visualisation expert can apply its domain-independent knowledge to prepare the data (aggregate, transform, classify, etc.), choose adequate display types and graphical primitives, provide an appropriate level of detail and degree of visual prominence for each information component depending on its relevance and criticality, arrange components in a composite display, and so on. If the user requests a standalone display for sending to another actor, he/she is expected to specify the intended output medium: a standard desktop or laptop computer, a small-size mobile computer, a mobile phone, a head-mounted display device, television, or paper. The visualisation expert will take into account the typical characteristics of this medium specified in its knowledge base: size, resolution, available colours, possibilities for dynamic output and user interaction, memory capacity, individual or public use. If the characteristics of the output medium permit, the visualisation expert may design a dynamic (animated) display and/or include appropriate interaction controls, for example, for zooming or switching between pages.

The design produced by the visualisation expert is implemented by a rendering component, which generates a corresponding information display on the screen of the user's computer. If the presentation is intended for a different recipient, the display serves as a preview and allows the user to edit the presentation, e.g. to change colours or symbol sizes. After user's approval, the rendering component generates either a static image or a presentation in SVG (Scalable Vector Graphics) format, which may be dynamic and include some interactive controls.

5. Examples and conclusion

The pilot prototype of the visualisation system is now under development. At the moment of writing this paper, it is capable of retrieving relevant information items depending on the type of event (e.g. fire or flood) and the task (e.g. detect potential sources of risk or find people needing help). The presentation design capabilities are limited to building maps where various types of objects are represented by symbols (icons), which may vary in size depending on the level of relevance or criticality. Some examples may be seen in figures 2-4.

We are gradually building up the knowledge bases and extending the capabilities of the prototype software. Thus, in the near future we plan to "teach" the system to work with complex spatio-temporal data and to handle large amounts of information by applying intelligent aggregation, classification, and filtering. By the moment of evaluation of the first prototype of the overall OASIS system, which will take place in August-September 2006, we expect that the visualisation system will be sufficiently intelligent and powerful to demonstrate the feasibility of the approach and the potential benefits for the emergency management personnel and for the population. We hope to receive feedback from potential users to take it into account in the further system development.

References

Andrienko N. and Andrienko G., 2006 Exploratory Analysis of Spatial and Temporal Data. A Systematic Approach. Berlin, Springer-Verlag

Casner S.M., 1991 A Task-analytic Approach to the Automated Design of Graphic Presentations. ACM Transactions on Graphics, Vol. 10, pp.111-151

Gartner G. and Uhlirz S., 2001 Cartographic Concepts for Realizing a location-based UMTS Service: Vienna City Guide Lol@, Proc. 20th International Cartographic Conference Beijing, August 2001, Beijing, China; vol.5, pp. 3229-3239

Kohlhammer J. and Zeltzer D., 2004 Towards a Visualization Architecture for Time-Critical Applications, In Proceedings IUI'04, Madeira, Funchal, Portugal, ACM Press, pp.271-273

Reichenbacher T., 2005 The importance of being relevant, In CD-ROM proceedings of ICC 2005 – International Cartographic Conference, A Coruna, Spain, July 9-16, 2005

Rosenthal U., Hart P., and Charles M. T. (eds.) 1989 Coping with crises: the management of disasters, riots, and terrorism, Charles C Thomas, Springfield, Illinois, USA

Rosenthal U. and Pijnenburg B. (eds.) 1991 Crisis Management and Decision Making. Simulation Oriented Scenarios, Kluwer Academic Publishers, Dordrecht, The Netherlands

Tufte E.R., 1997 Visual Explanations. Images and Quantities, Evidence and Narrative. Graphics Press, Cheshire, Connecticut

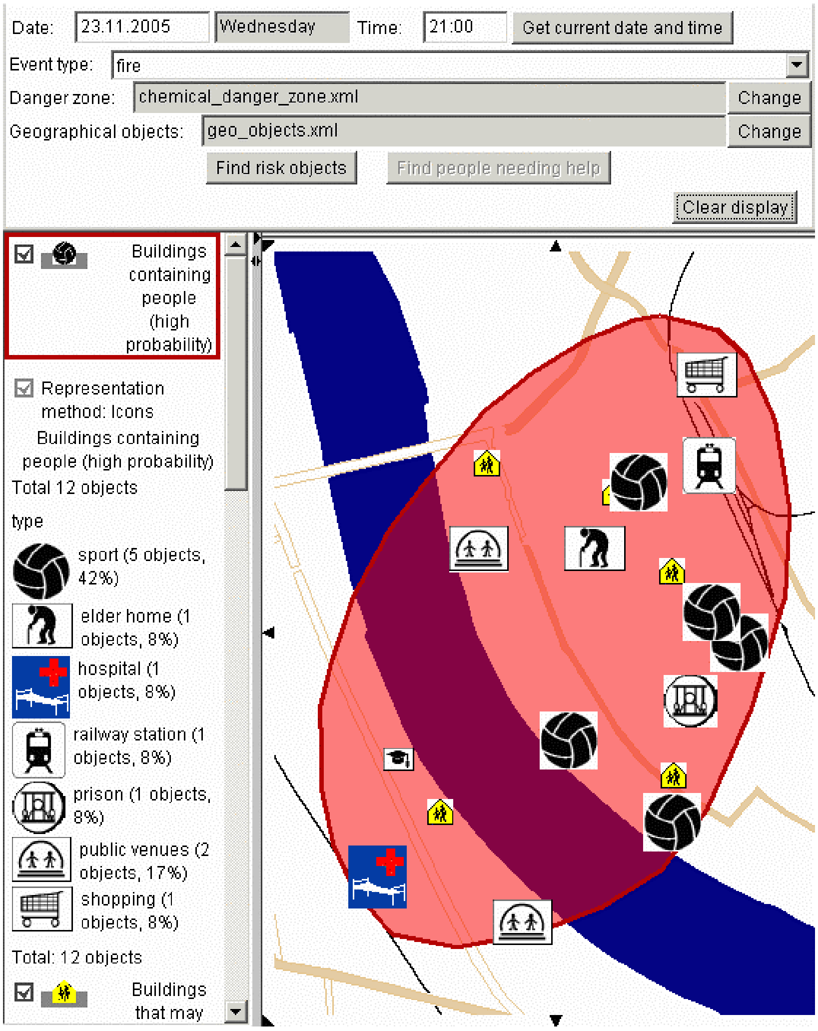

Figure 2: A display presenting the buildings that may contain people needing help in the situation of fire occurring in the evening on a weekday. The sizes of the symbols correspond to the degree of relevance (in this case, the probability of people being inside the buildings at the specified time of the day).

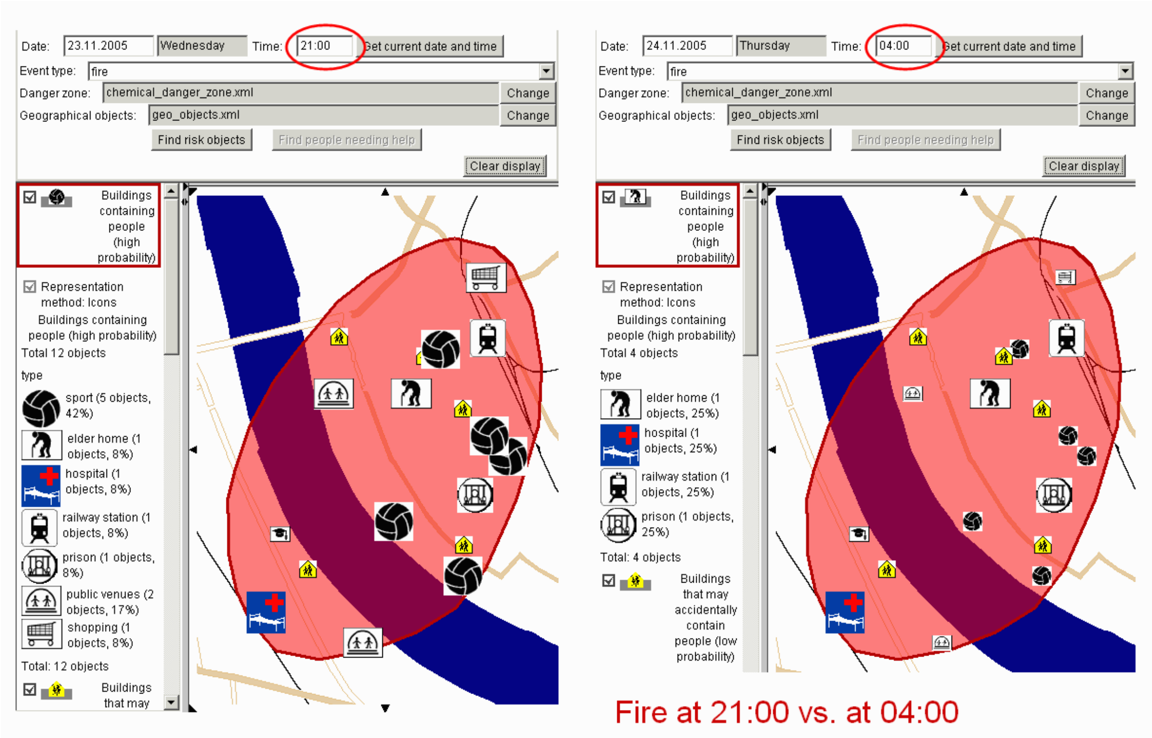

Figure 3: Depending on the situation specifics, the same information may have different relevance and, as a result, given different visual prominence. This figure demonstrates how the time of event occurrence influences the appearance of the display of buildings with people needing help.

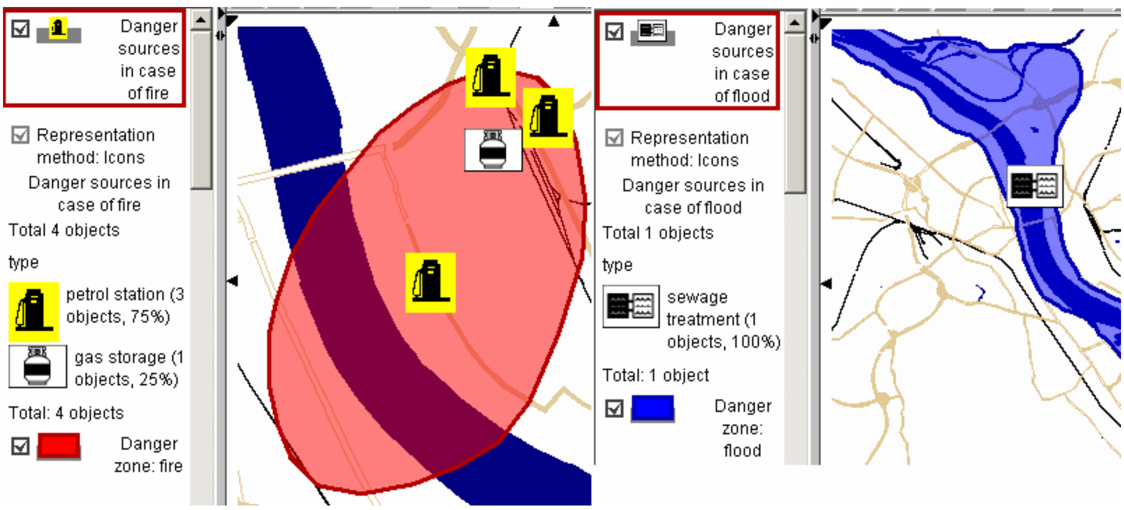

Figure 4: Two screenshots from the displays representing the potential sources of risk in the situations of fire (left) and flood (right).