SPATIO-TEMPORAL KNOWLEDGE REPRESENTATION AND ANALYSIS FOR EARTHQUAKE DISASTER MANAGEMENT

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ABSTRACT

This paper examines the importance of integrating different spatial and temporal knowledge representations in order to structure disaster relevant information. Special focus is made here on the human-machine interface. An overview for structuring the knowledge is presented within the framework of a technical information system. The idea of configuring the relevant knowledge with templates for spatial reasoning is extended for collaborative spatial decision making. The architecture of a system for co-operative decision making is then outlined. This provides a means for co-operative disaster management. A central part of this system is the messaging system. The specifications and main characteristics for such a messaging system are presented. An example implementation is then given.

1 INTRODUCTION

As experience has clearly demonstrated, the management of disasters will continue to constitute one of the serious technical and social issues of the 21st Century. The collaborative Research Center 461 located at the University of Karlsruhe is in the process of developing a disaster management tool (DMT) to support effective rescue measures after earthquake disasters. One part of this DMT is the technical information system (TIS). The TIS is basically a tool for group planning that facilitates the mediation of the best solution to solve a given problem and allows for information analysis in the disaster management process. Up to now, information systems for disaster management are not well adapted to the needs of group decision making. In recent years, several approaches for supporting disaster management through the use of knowledge representation and artificial intelligence have been developed. These have been introduced in different fields such as the management of floods, wild-fire, earthquakes, etc.

In Todokoro et al (2000) and Kitano et al (1999), the main challenges in disaster management are highlighted. These are divided into four problem domains:

- a comprehensive disaster simulation for damage prediction;
- an agent system for mission planning;
- a real world interface for data collection and automatic control of infrastructures, and
- the human-machine interface.

In this paper we concentrate on the human-machine interface. While it is obvious that computers cannot replace the human decision maker with autonomous software programs for disaster management tasks, there are several arguments for using automated systems as discussed in Ferguson et al (1996). For instance:

- there is a surplus of data, only a small amount of which is actually information relevant to the current task;
- the situations being considered are large and complex, and it is therefore beyond human capability to manage all the details effectively;
- automated planning systems are basically able to handle scale. However, such systems are hard to supply because of the under-specified initial situations and the fact that many planning decisions are made on an intuitive basis.

The apparent result of the above scenario is that neither the computer nor the human can effectively solve such management problems in isolation.

But not only is the human-computer interaction critical within the context of disaster management. Even more important, however, is the computer supported collaborative decision making of a set of human decision makers. The principle goal should be a homogenous co-operation between software agents as artificial decision makers and human decision makers. Both the human being and the computer will have their own optimal communication interface. That is why one cannot employ the same communication descriptions for a human like those used for a computer. Moreover computers are not able to understand all ways and intricacies of human interaction. Examples here include natural language, sketch-like descriptions etc. The conflict resolution of a team of decision makers (as well as simulated decision makers) is itself a challenging problem. The first step to building an argumentation framework is to represent the existing knowledge in order to:

- provide a possibility for storing expert knowledge;
- actively identify typical situations as they arise; and
- give the possibility to formulate intentions and beliefs of the planner.

2. SPATIO-TEMPORAL KNOWLEDGE REPRESENTATION

Every disaster management system has to have its representation of the surrounding environment. Reasoning about the knowledge requires a formal description of the knowledge. For example, this may include descriptions of fires, housing and building damages, disruption of transportation channels, electricity, water supply, gas, and other infrastructure, movement of refugees, status of victims, hospital operations etc. Basically, there are two conflicting goals in attempting to formalise disaster relevant information in advance:

- The description of the problem has to be general in order to cover as much different occurring situations as possible. The more general the description is the less meaningful are the results of reasoning.
- The description has to be as detailed as possible to achieve meaningful statements. The more detailed the description is the less are the number of use-cases.

First of all, we have to know whether an object exists or not. In other words, there has to be an identity. If we are aware of the existence of an object then we may be able to embed it in space and time. There is also the fact that the information about identity space and time may be inaccurate, conflicting and/or incomplete. Furthermore, the reasoning will be performed at different levels of abstraction.

2.1 SPACE

Disaster managers often use maps to discuss and sketch their long time strategies. Some examples for using GIS-maps for disaster response are shown in [Amdahl, 2001]. This illustrates the relevance of spatial knowledge. In the case of spatial reasoning one has to distinguish between two types of spatial knowledge (Habel et al 2000):

- Determined Geometry: The absolute and metric geometry of the described objects is known (points, polygons, surfaces, etc. described by co-ordinates). Examples for a determined geometry may be some objects in a GIS, from a map, from GPS-receivers carried by the SAR-teams, remote-sensing for airborne reconnaissance, computed by simulation in time for instance by velocities of a unit, name of the street of the location etc.
- Underdetermined Geometry: Constraints, relations or directions described by natural language description of spatial knowledge in messages and reports of the disaster situation. For example, in describing the structure of a damage, the direction the debris has fallen may be given. "Naive" descriptions of spatial planning knowledge also include examples like the "smoke of the fire is drifting

north", or the need that one tactical unit has to be placed next to another. Theoretical work on such descriptions is found in Egenhofer (1989).

2.2 TIME

Similar to the representation of space one can basically distinguish between two levels of detail in the description of time:

- The duration and time points are completely known: In some cases there is knowledge about the duration of tasks from experience or estimation. The time point of an event may be known from simulation or a message sent to a certain time. Formalisations for temporal reasoning have been discussed in Allen (1991).
- Only the relations between the time intervals are known: Sometimes only incomplete and approximate knowledge exist about duration of tasks or only the necessary order of the tasks (e.g. in the order of states) is given. Some events of disasters are related to each other . For instance, an earthquake results in the collapse of buildings, the collapse of buildings affects the spread of fire etc. Here a generalised form of the approach of Allen (1991) is required to model these temporal relations. Such a generalisation is described in Freksa (1992).

Therefore, a significant part of the disaster relevant space and time knowledge will be in a underdetermined form. As a result of this, it is necessary to provide means to reason based on topological relations and constraints.

3 STRUCTURING THE KNOWLEDGE

In the case that events are modelled as objects themselves, the message, understood as the basic unit of communication, is a composition of different objects. The main difficulty is to get a correct representation of the content of the message in a formalised form. Usually this is done by hierarchically ordered forms in blackboard systems, see for example, RIMS (2001). This kind of representation can only be used to a limited level to reason on the contained information. Therefore, we suggest the extension of the forms with visual concepts for knowledge description. The description in space is based on the usual geometry concepts. Relations in space can be represented by symbols such as arrows or graphs. The nodes are the events while the edges are the relations which are also specified by symbols. The relations in time can also be represented by graphs.

The elements of the messages themselves can now be structured again. This corresponds to the idea of the templates for spatial reasoning as discussed in Williams (1995). In this work, messages are merely related to each other. However, sometimes it is even necessary to relate the elements of the (different) messages to each other. To achieve this, not only do the messages need to have a spatial and temporal context, but also the elements of their content. The variety of objects and the variety of relations has to be extended as well e.g., to describe the change of the socio-economic units Worboys (1998) or other spatial and temporal relations. This is required in order to define intentions, beliefs, predictions or explanations as complete as possible.

In Figure 1 the principle of the TIS Architecture is outlined. The messaging system enables the decision makers (or in the case of an exercise the simulated decision makers) the chance to structure and formulate their beliefs, intentions and specifications as described above. On the one hand, the messages are stored in a spatio-temporal database which can be used for documentation and analysis of the history of the disaster. Alternatively, this knowledge is transformed into the corresponding facts and rules. The facts and rules are the formal description of the structured objects defined in Chapter 2. In an inference machine, these descriptions can be analysed to detect conflicts. The conflict resolution should be as much as is possible automatic. The Messaging-system and the inference machine are fed also by knowledge from a knowledge-base. Up to now, only the messaging system and knowledge-base are implemented.

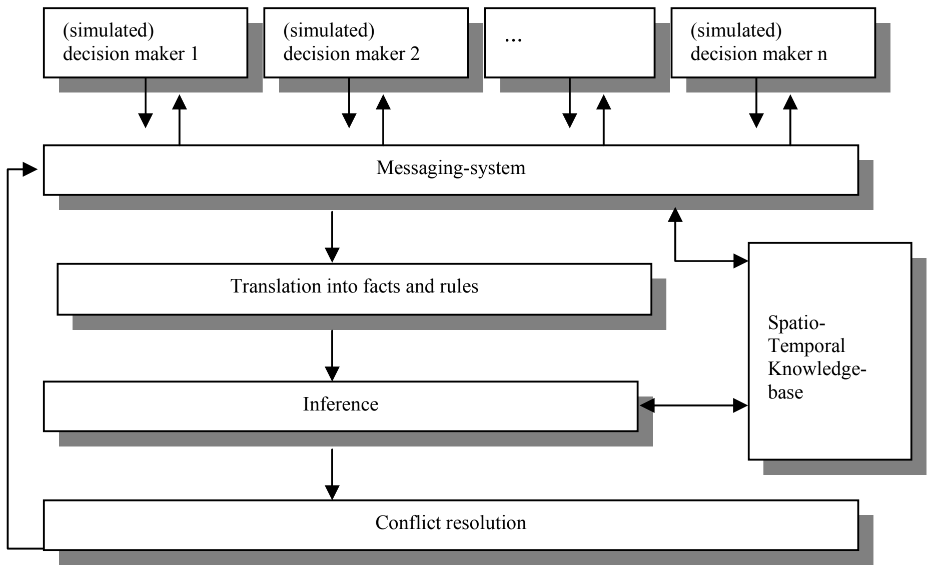

Figure 1: Principle of the TIS Architecture

4 MESSAGING-SYSTEM

The Messaging-System is built as an client-server architecture as shown in Figure 2. This is necessary because of the fact that there are multiple planners working on different places to solve perhaps different problems. On the server side, the Java 2 Enterprise Edition (J2EE) is used. J2EE is based on API specifications for communication technologies for distributed objects, e.g., CORBA, RMI, and Java Message Service (JMS) for asynchronous communication, component technology for Internet based service (Servlets and Java Server Pages) and Enterprise Java Beans (EJB). It also contains the access possibilities of relational Databases, mail service and directory services.

The server services of J2EE are mainly used for asynchronous communication between the individual clients to exchange information. In asynchronous communication the sender and receiver must not simultaneously keep open the network link to guarantee exchange of messages. This is in particular important for disturbed life lines in a disaster area.

The implementation of the JMS in the J2EE serves as a mediator between sender and receiver (Message Oriented Middleware, MOM). Incoming messages are asynchronously calling the relevant components (Message Driven Beans) inside the J2EE server. The contents of these messages are saved in a suitable form in a DBMS. It will be possible to describe the content of the message with geographic concepts: it should be possible to transfer sketches that describe the situation with predefined objects like tactical units, campaign areas, damages, hazards, etc. In Figure 3 is shown on the left side an overview of the tactical units. On the right hand side one can see the tactical symbols for units, damages, actions, institutions, etc. Besides their respective content, the message also contain meta-information of e.g., the sender, receiver, as well as the geographic origin of the message. In the employed PostgreSQL database there is a spatial module contained that delivers some the necessary geometry-types used for this (PostGIS). This spatial module is still under development and will be an OGC-conform implementation of the simple-feature specification (OpenGIS 2001). The desired spatial and temporal reasoning can only be done to a certain extent by conventional GIS. Complete reasoning requires an extension in order to represent the above temporal and spatial aspects.

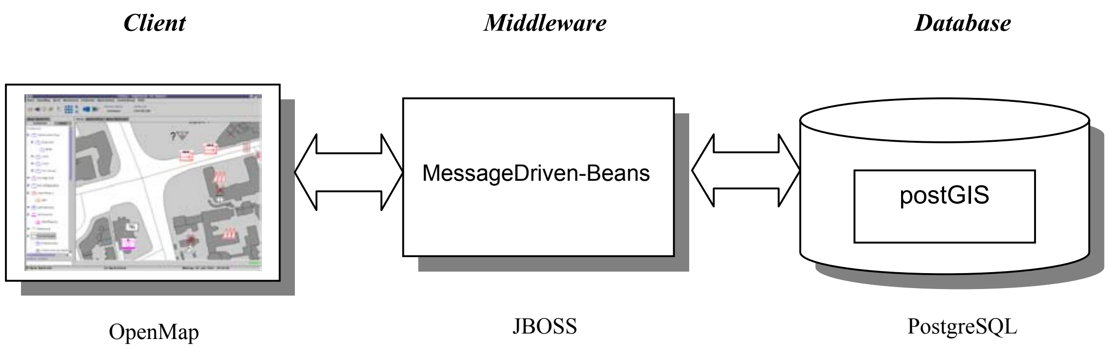

Figure 2: Overview of the messaging system

Besides saving the data, the message driven beans can also been used to transform the Java-Objects of the JMS messages into a suitable XML-Structure. This can then be used to facilitate the communication with non J2EE systems. The client consists of a Java-Swing based user interface (OpenMap). There is the possibility to compose messages, the available resources and their status can be seen in a hierarchical structure. Further details to the GIS-messaging-system can be found in Wursthorn (2000).

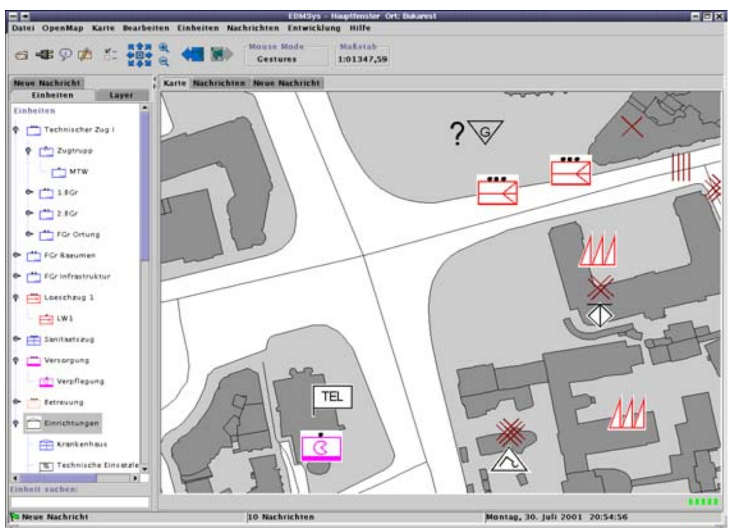

Figure 3. Part of the GUI of the GIS messaging system for tactical planning.

4 CONCLUSION

In this paper we have attempted to show the importance of integrating different spatial and temporal representations to formalise and reason conflicting, inaccurate and incomplete knowledge about a disaster situation. The idea of structuring the relevant knowledge with templates for spatial reasoning is extended to collaborative spatial decision making. The current state of the developments are presented.

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