MIND – Methods and Tools for Visualization of Rescue Operations

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Abstract

Visualization of rescue operations and exercises can help responders and managers to learn from experience. Detailed visual models of the response to various emergencies enable them to systematically identify strengths and shortcomings in performance as well as in plans, procedures and equipment. We describe a method and a software tool for capturing the activities of the responding units during a real incident or exercise to create a self-contained visual representation of the operation. This model can then be replayed and analyzed. The software tool provides a flexible and extensible environment that can host models and visualization components for many different types of operations. Because the environment defines a set of plug-in interfaces it is straightforward to add new components to meet arising needs for new types of data and presentation views. We present the essential features of the software and show how we used it in a field trial.

Introduction

Maintaining and improving the quality of rescue services requires continuous and relentless attention to plans, procedures, equipment, and performance in operations and exercises. Ideally, managers, commanders, and team members scrutinize every operation and exercise to find the strong and weak points of their organization and the tactics and procedures used (Flanagan, 1954; Raths, 1987; Salas et al., 1992; Fredholm, 1996). In this way shortcomings can be rapidly identified and remedied, and strengths can be recognized and reinforced. Unfortunately, this procedure is severely hampered by the lack of appropriate methods and tools not only for capturing the essential aspects of a rescue operation or exercise, but also for documenting them and presenting them in a coherent and comprehensible manner to a wide audience in a rescue organization. As a consequence, it is difficult to use exercises and operations as a basis for the systematic development of an emergency-response organization.

We have addressed this problem by presenting a method for systematically documenting and visualizing rescue operations together with a computer tool that supports the implementation of the method (Morin et al., 1998; Morin et al., 2000). Our main assumption is that it is necessary to prepare documentation and visualization *before an operation* by means of proper *instrumentation*. Instrumentation is the process of ensuring that the necessary means of collecting and presenting data from a rescue operation are present before it takes place. To succeed, this process has to balance extensive data requirements with practicable data collection methods. The goal of our approach is to provide methods and tools to help the response organizations to conduct an appropriate instrumentation and eventually to empower their members to learn systematically from their work.

In this paper we concentrate on the visual representation of data from rescue operations and exercises. We show how we construct this representation by compiling data collected during an operation and transforming them into an executable model that can be visualized by a special software tool. However, what constitutes appropriate views and styles for presenting such information are still an open research issue. As a consequence it is important that the visualization tools can be extended and modified to support experiments with alternative means of presenting operational data. To this end we present a software framework that accommodates multiple visualization views as replaceable *components*. To be eligible for execution these components must follow a well-defined protocol for interacting with the framework and for coexisting with other components. We provide an overview of the features of the framework, the component architecture, and the protocols and interaction patterns.

The rest of the paper is organized in the following way. In the next section we describe the various steps of the instrumentation method. Two sections follow, which deal with the visualization of rescue operations: the first one discusses visualization principles for temporal information and the second one describes the MIND visualization framework. Then we describe a field trial where the method was applied to a subterranean exercise involving a train derailment in the Stockholm Underground. A discussion section and our conclusions round up the paper.

Instrumentation Method

Many of the problems we encounter when we attempt to analyze rescue operations are caused by insufficient data. The following list includes some typical examples of such data problems:

- Individual recollections cover fragments of the operation from particular locations and at specific time points.
- Individual recollections are subject to personal bias.
- The timing of observations is neither sufficiently accurate nor synchronized with a common global clock.
- Face-to-face communication and telecommunications are inaccessible.
- Data are contained in proprietary, inaccessible systems.

- Physically accessible data come in incompatible formats.

Reconstructing an operation based on this type of data is a complicated and time-consuming process. Its outcome is to a great extent determined by the analysts' interpretation of data. Opponents can always question the validity of their conclusions by offering alternative interpretations of data. For this reason it is difficult both to establish a factual account of the course of events of an operation, and to analyse the decision-making processes underlying and controlling these events. As a consequence, it is difficult to establish a common ground for learning from experience in operations and exercises (Allen, 1997; Rouse et al., 1992). Clearly, there is a need for more systematic approaches to data collection and mission reconstruction.

Our instrumentation method addresses the problem of how to transform operational objectives into goals for the visualization of the operation, and how those goals direct the modeling of the operation. The end result of this undertaking is a *mission history* (Morin et al., 1998), which is an executable, discrete-event model of the rescue operation. The method includes the following six steps (Morin et al., 2000):

1. *Scenario analysis*: The purpose of scenario analysis is to identify critical areas that affect the outcome of an operation, for example critical resources, limiting factors and parallel activities that require careful coordination and management. The output of this analysis is a list of areas and activities where visualization can help people to understand rescue processes and cause-effect relationships.
2. *Focus of attention*: The goal of this step is to establish the primary goals for modeling and visualization, for example by identifying the objective functions and their defining parameters as a basis for devising models and data collection.
3. *Scenario modeling*: Modeling the objects and events of the scenario defines what aspects of the scenario will be represented by data and how these data will be visualized. Object attributes and state variables are defined together with the events that define state transitions. This step includes verification that data can be collected and visualized. Thus, modeling bridges the gap between objectives and the actual representation.
4. *Data collection*: Data collection takes place during an operation to register the events that occur and the resulting object state transitions.
5. *Visualization*: The data collected are transformed to a corresponding visual representation to make conditions, circumstances and relationships visible. The form and style of the presentation has to be adapted to the target audience.
6. *Documentation*: The purpose of this final step is to package models, data and procedures in a format that is comprehensive to a professional audience and easy to access and distribute. One example is to build an archive on the Internet or on an intranet of models, observations and lessons learned to support education, training, evaluation and development (Jenvald et al, 2000a; Jenvald et al, 2000b).

Instrumentation requires an intimate knowledge of the operational scenario and great familiarity with the advantages and drawbacks of various data collection methods. Therefore, it should be jointly conducted by domain experts and experts on the design of field experiments. Together they define the objectives of data collection and visualization, prioritize between competing requirements, and establish a detailed data collection plan. The precision, accuracy, and frequency of various data sources have to be analyzed and compared to devise an acceptable solution. In some cases this process is initiated for a single exercise or field trial. But in general it is desirable to design a working instrumentation for a class of similar scenarios, where a particular operation becomes an instance of such a scenario.

Visualization of Temporal Data

Visualization is the means of turning a model of a rescue operation into a visual representation that is suitable for browsing and manipulation by human users. One part of the visualization problem is to identify appropriate views for displaying different types of data—for example, position logs, digital photographs, audio recordings, and observation protocols. The other part of the problem is to devise mechanisms for coordinating multiple views, which preserve the spatial and temporal properties of the data presented. Because all data collected must have an associated time stamp from a common global clock we use time as the primary coordination mechanism.

Time-stamped data correspond to events that define state transitions in the model of the rescue operation. We use this fundamental relationship between observations in the real world and state transitions in a model of an operation to define the following means of visualizing operational data:

- *Snapshot*: A snapshot (Figure 1a) is a visual representation of the observable state of an operation at a particular point in time, which allows a user to explore the state of the operation at that time. Using multiple views the user can filter out irrelevant information and zoom in on interesting objects to look into the details of the operation.
- *Time line*: A time line (Figure 1b) identifies a set of states in a time interval. It is the primary means of providing overviews of operations. Filtering and clustering help the user to partition large data sets into smaller ones that relate to particular units or specific activities. Time lines support navigation as selecting a state on a time line can produce a corresponding snapshot.
- *Animation*: An animation (Figure 1c) is a time-driven, visual rendering of successive states in the model over a time interval. Much data from rescue operations form patterns over time that may be far more interesting to study than each individual sample, for example, the area covered by a search and rescue party.
- *Multimedia stream*: A multimedia stream (Figure 1d) is a data flow such as a video sequence or an audio recording. Although a multimedia stream may consist of discrete samples, the resolution of the clock used to synchronize them is typically significantly smaller than the resolution of the common global clock used to order events in our discrete-event model. Therefore the beginning of a multimedia stream can be represented as an event, but not its individual samples.

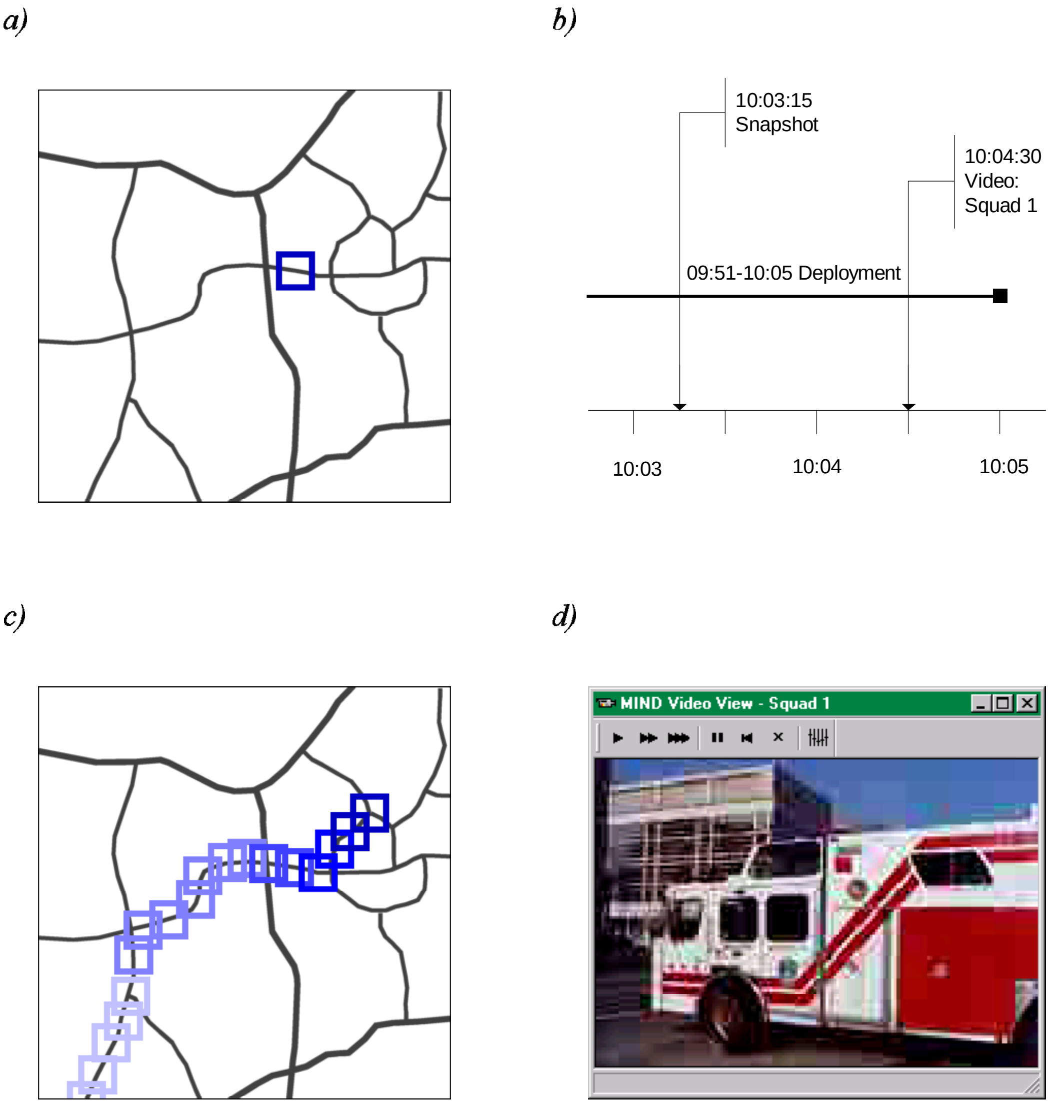

Figure 1: Four means of visualizing temporal data. **a:** Snapshot. **b:** Time line. **c:** Animation. **d:** Multimedia stream.

In all these visualization techniques time is used as the mediator between representations. A time line provides an overview of events that correspond to state transitions at specific time points. Snapshots provide the details of selected states. Animations show successive states to create an illusion of movement and development over a time interval. Streams present a special case in that their replay is asynchronous with respect to the common global clock.

Visualization Framework

Technologies such as COM and CORBA (Orfali et al., 1996) provide protocols and tools for building software from self-contained, interoperable components. Components expose their functionality as interfaces, which are the only means of interacting with a component. In our approach the model of an operation—including its visual representation—is built from various types of components. The visualization framework provides a protocol for interaction between the components by defining a set of mandatory and optional interfaces. It also defines a computational architecture that accommodates the components and prescribes the sequence of activation and execution.

Creating a mission history for an operation is a matter of representing various aspects of the operation as components in the visualization framework. The main component types in the MIND visualization framework are the following:

- *Objects*: Objects model real-world elements of a rescue force, such as vehicles and people. Objects can be organized hierarchically to model the structure and chain of command of various rescue organizations. State variables capture the essential aspects of an object such as location, capabilities, and resources.
- *Events*: Data collected during an operation correspond to events. Events define changes in object state variables at particular time points represented by time stamps. Events are closely related to data collection. Adding new types of data requires additional event components.
- *Sources*: Every event is associated with a source to enable information tracing in the system. This mechanism makes it possible to maintain chains of evidence that corroborate conclusions about the operation.
- *Views*: Views are visualization windows for particular types of data. Customized view components are the primary means of extending the visualization capabilities in MIND.
- *Maps*: Map components provide important geographical information. Because this information is dependent on the particular representation (that is, coordinate system) it has to be customizable and extensible. Thus, a map component encapsulates a model of the earth, a projection method, and the logic necessary to render an image of this model.
- *Documents*: Document components come in many forms, for example text, digital photographs, video clips, audio samples, local HTML pages, and Internet URLs. They can be used both to include background information such as regulations, instructions, and plans, and to represent observations and records captured during an operation.

When the mission history has been completed it can be loaded into the MIND Explorer for replay. This tool maintains a time-ordered list of all events and a virtual clock. By setting the speed of this clock the user controls the animation of the operation. At any time the user can stop the clock to inspect a snapshot of the operation or replay a multimedia stream. The user can move between snapshots by selecting arbitrary time points either from a time line or from the replay control panel.

Field Trial

We have implemented several versions of the MIND framework as a part of an iterative research and development process. An essential phase in this process is the field trial where the methods and tools are tested in a real scenario with real users (Morin et al., 1998; Thorstensson et al., 1999a; Crissey et al., 2001). The component-based framework was field-tested at a multi-agency exercise in the Stockholm

Underground. In this operation a large rescue force responded to a subterranean train derailment in the center of Stockholm.

Scenario analysis together with representatives for the various agencies revealed that the main problems were related to the command and control of the operation. The focus of attention was placed on the function of the field command post where commanders from the fire-rescue services, the police, and the emergency medical services coordinated the operation. But to delimit this function we also needed to cover its interaction with the rescue units as well as with rear-echelon command. Furthermore, to assess the effect of the command and control efforts we monitored the deployment of the forces and the extrication and transportation of casualties from the accident scene to three hospitals. The models used in this operation were fairly simple and mainly represented the type and position of the units. We collected large numbers of data from several sources during the 3-hour operation. Position data were collected using the global positioning system (GPS) and by human observers. Observers also provided comments and digital photographs from critical functions and phases of the operation. Extras, acting as casualties, tracked their own progress and treatment in the chain of medical attendance from the train to the hospital. Video cameras were used to capture the operation. A lot of information regarding the command and control was obtained from digital recording of 10 communication channels.

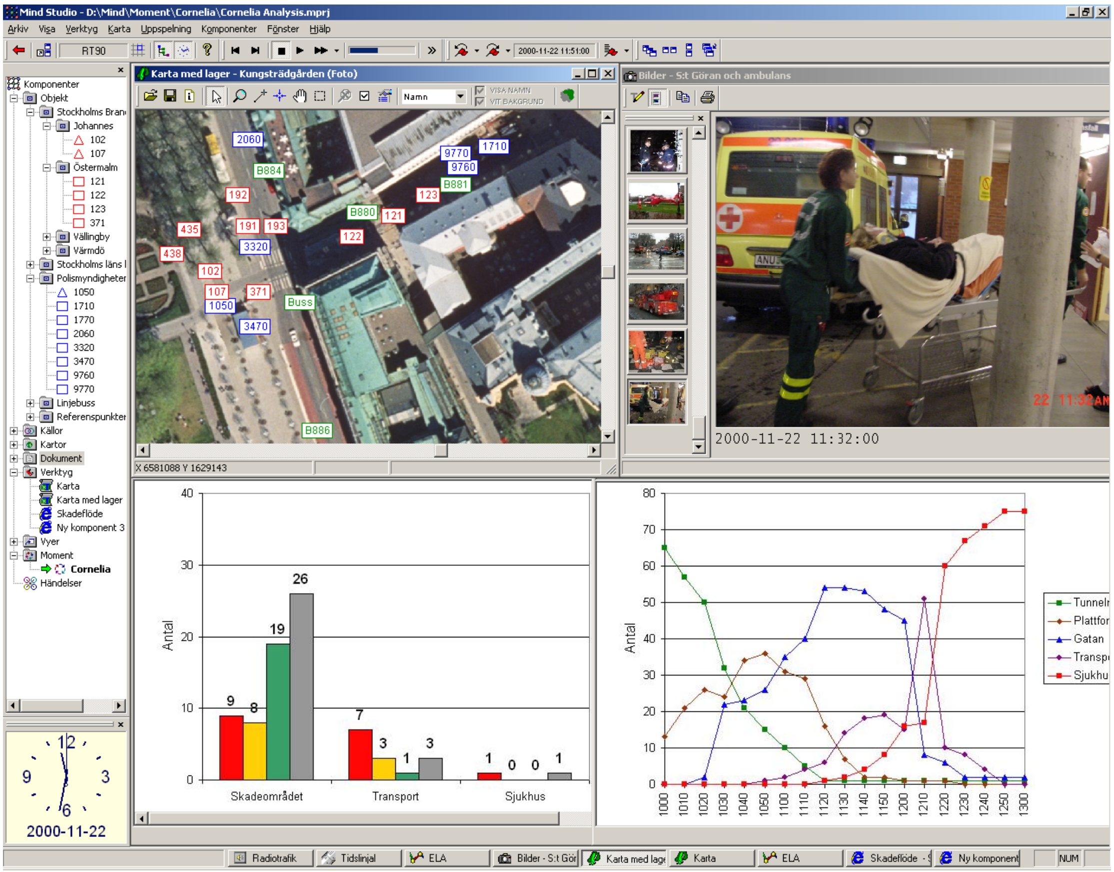

Figure 2: A screen shot from the MIND system during the replay of the exercise. Starting from the top-left corner and going clockwise it includes a component tree, a map view, a photo view, a summary of the treatment of casualties, a diagram of the casualty distribution, and a replay clock.

To visualize the data from the operation we had prepared several views. Three hours after the operation a subset of the data was presented to the participants at an after-action review. It included an animation of position data in map views, diagram snapshots showing the transportation of casualties, digital photographs, and replay of digitally recorded radio communications (See Figure 2). Video clips were not included at this point.

After editing videotapes we added visualization views for displaying video streams (See Figure 1d). This extension was straightforward and included adding a new document component for video and a new view component for presenting video streams. Similarly, we added components for presenting communication patterns based on digitally recorded radio traffic. A dynamic time line (Figure 3) was added to provide a sliding view of the events registered in the time interval surrounding the present time point of the virtual clock. Using this time line the user can detect upcoming events before they take effect and focus on the appropriate views. This function is especially important when there are many active views.

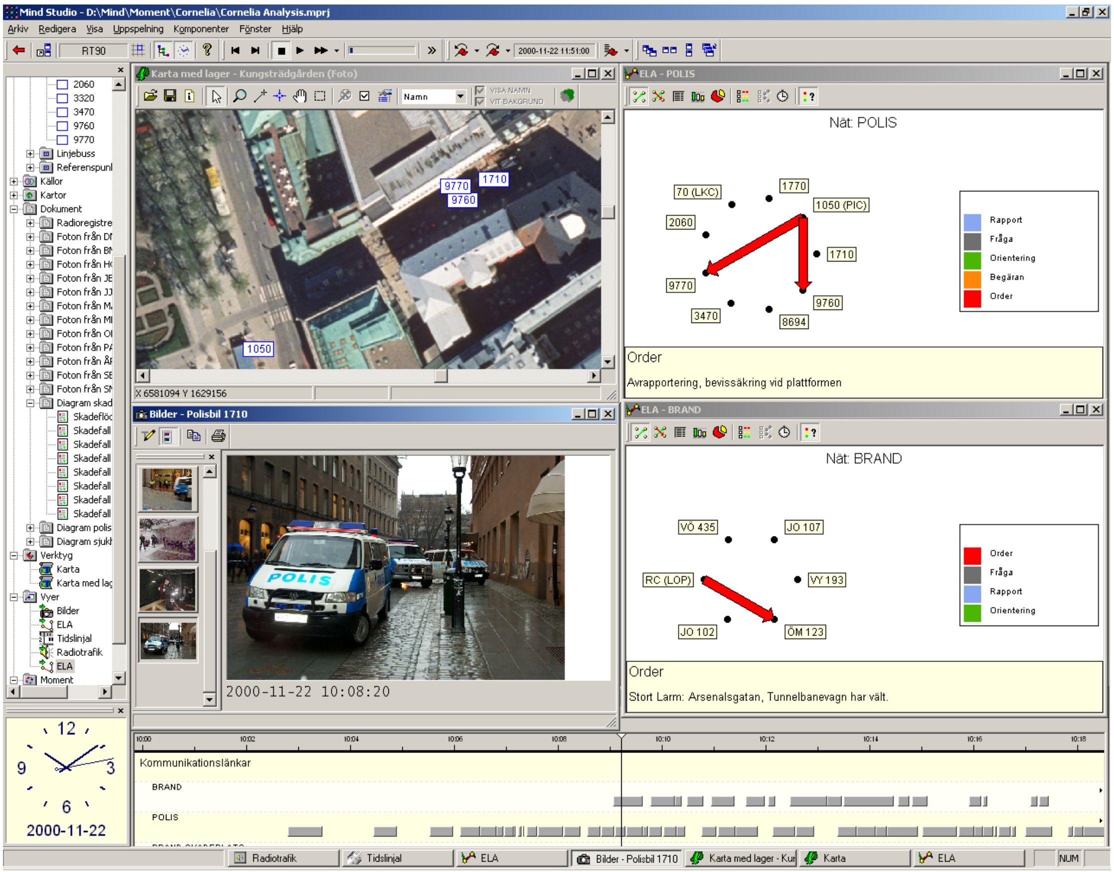

Figure 3: A screen shot from the MIND system focusing on communication analysis. At the bottom is a dynamic time line indicating communication events. The views to the right show the result of analysing this communication by displaying arrows from sender to receiver in colors indicating the classification of the messages.

Discussion

Visual representations of operations and analysis results are important means of communicating the results of documenting and analyzing rescue operations. However, we need to explore effective ways of presenting the information to different prospective audiences. Working close to the end-users in an iterative manner allows us to tune the visualizations to meet their needs. The component-based framework supports the design and implementation of visualization views by providing protocols for the interaction between models of domain objects, operational data, and visualization components. Reusable software modules that implement core functions in this interaction complement these protocols. Thus, developers can concentrate on the visual representation of data—the framework provides the infrastructure.

The field trial showed that the framework indeed supported the rapid development of new visualization components. A video clip viewer was added to provide a view for a type of data not previously included in the framework. Also, a dynamic time line was added to provide a new view of existing data. These undertakings clearly indicate that the framework is indeed extensible.

Conclusion

Documentation and visualization of rescue operations and exercises are important means of improving the quality of rescue services. To support this process we need appropriate methods and tools. The MIND visualization framework presented contributes to this development by providing essential infrastructure for experimental design of visual representations of rescue operations.

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Biography

Magnus Morin is an independent consultant specializing in software architectures for information systems. His research interests include methods and tools for collection and visualization of data from operations and exercises. Mr. Morin holds a M.Sc. in Electrical Engineering from Linköping. He is a Ph.D. candidate in Computer Science at Linköping University.