REPRESENTING UNCERTAINTY IN SITUATION MAPS FOR DISASTER MANAGEMENT

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Abstract

Emergency staff perform their task under mental and time pressure, especially when leading the emergency operation on-scene next to the damaged area. The mobile command vehicle provides lots of supporting tools to conduct the operation successfully. We here focus on the situation map. It is used by the emergency staff to provide an overview of all operational information at a glance. The map contains certain and uncertain information, which is to be displayed differently. In this work we analyse the state-of-the-art uncertainty representation both from a theoretical and practical point of view, and examine alternative uncertainty representation techniques. We propose two new techniques to display uncertain information. In an empirical evaluation we show that these techniques allow a higher performance of the map-reader than the state-of-the-art technique in terms of classifying the displayed information correctly. Given that there is reduced space for the situation map in a mobile command vehicle compared to stationary emergency operation centers, space-saving uncertainty representation proposals could be particularly interesting for displaying situation maps on smaller screens.

1. Application domain and requirements

The situation map is an important tool to support emergency staff. It plays a key role during the emergency management process as the sole source for an overview of the emergency situation at a glance. For this purpose, the relevant operational information is depicted on the map using a specific symbol set which represents damages and dangers. In this context, it is necessary to distinguish between certain and uncertain (e. g. incomplete or probably incorrect) information, because uncertain information critically affects human resources planning. The German emergency operations manual refers to this requirement by specifying a particular representation of uncertain information in situation maps **[1]**. In this state-of-the-art representation uncertain information is marked by preceding the coding symbol by a question mark "?". Figure 1 shows an exemplary situation map. It has been verified by a professional fire-fighter, experienced in conducting operations in mobile command vehicles.

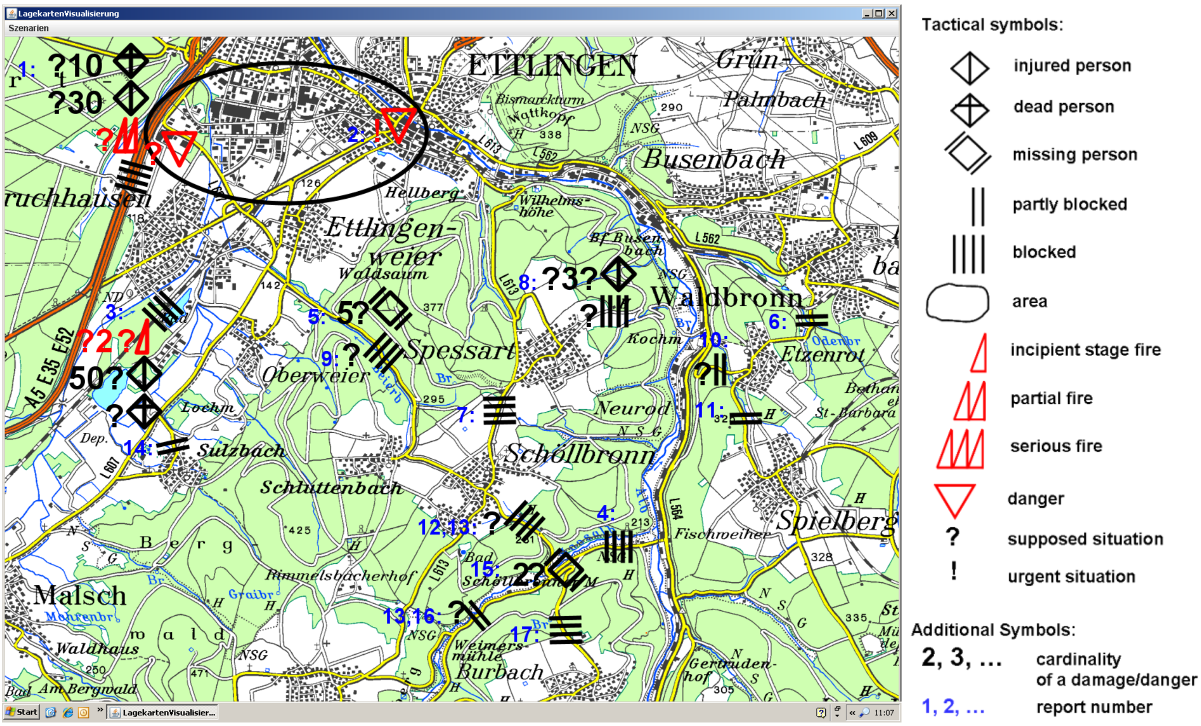

Figure 1: Exemplary Situation Map

Especially when leading the emergency operation on-scene next to the damaged area, emergency managers perform their tasks under high mental and time-pressure. It is therefore particularly important for them to focus on their major task of conducting the disaster operation. In consequence, any ancillary task should be easy to carry out, i. e. with minimal cognitive load, especially for the short-term memory. With respect to the usage of the situation map, this can be achieved by a plain and clear visualization of the relevant operational information as well as an easy interpretable discrimination of certain versus uncertain information.

In this work we examine representations of uncertain information in situation maps. The aim of our investigation is to minimize the cognitive load of the human map-reader by finding an optimized representation for uncertain information. Additionally, a space-saving representation could be particularly useful for displaying situation maps on smaller screens, as found in narrow mobile command vehicles.

2. State of the art

The basis of our work is the state-of-the-art representation of situation reports by situation maps. The base map for our situation is a commonly used topographic map. We have chosen this type of map because of its detailed graphics, due to which it is difficult to easily detect tactical symbols at arbitrary locations on the map. A representation which works on this type of map would also work on every less detailed map. Furthermore, topographical maps are available both as analogous and as digital maps. Although situation maps are still often paper maps, we decided to to follow our fire-fighter, who pointed out lots of advantages of using digital situation maps; especially when supporting emergency operations in far-off areas, loading the corresponding map from the internet allows to start with preparing the situation map already on the way to the damaged area. As symbol set we use the German tactical symbols as specified by the German emergency operations manual **[1]**.

As a basis for finding appropriate uncertainty representation techniques we present a hierarchical overview of the status quo of the research in this domain, focussed on contributions by the cartography and scientific visualization community **[2, 3]**. As a result we get the tree-structure depicted in Figure 2: In the leaf nodes currently used representation techniques are listed, while the inner nodes describe their representational properties.

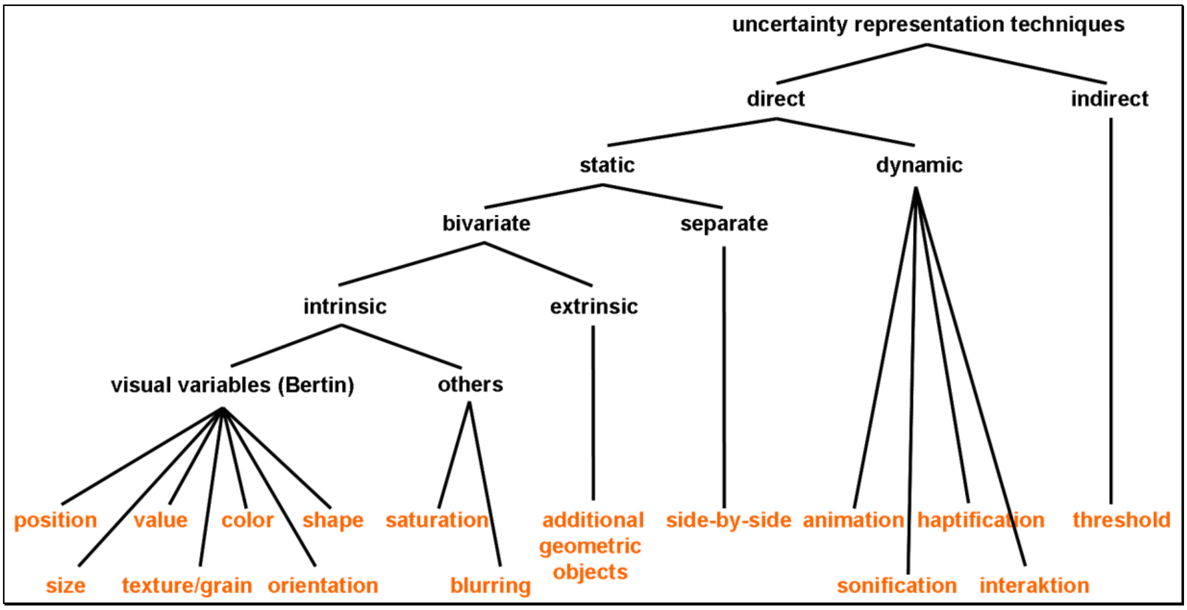

Figure 2: Taxonomy of Uncertainty Representation Techniques [4]

As assessment criterion to decide on the suitability of a representation technique we use findings from the human engineering area. We consider the aspect of a representations' conspicuousness as well as the aspect of the limitation of human perception as described by the Model Human Processor **[5]**, especially focussing on the bottleneck nature of the short-term memory for the human cognition as a whole. Concerning this matter, a key requirement is to find an uncertainty representation which occupies as few chunks as possible in the short-term memory.

3. Theoretical results

In our work uncertainty is displayed as binary information – i.e., the operational information is assumed to be certain or uncertain, without any intermediate levels in between. It has been shown that the mapping between human statements about uncertainty and numerical measures for uncertainty, such as probability, is difficult **[6]**. Considering multiple assessments of a dangerous situation, – for example first by the investigating fire-fighter, second by the staff member in the mobile command vehicle, who decides on the symbolic representation of the report in the situation map – the ambiguity in the interpretation of the uncertainty degrees could lead to manifold misinterpretation. This is not acceptable in a high-stress emergency situation.

3.1 State-of-the-art technique (*„?"-technique*)

The state-of-the-art technique introduced above, subsequently called *„?"-technique*, displays uncertainty as binary information. Certain information is depicted by a corresponding symbol, while uncertain information is displayed by the symbol preceded by a "?" mark. Looking at the tree in Figure 2, the *„?"-technique* can be classified as *direct*, *static*, *bivariate*, *extrinsic*. The "?" is one possibility to add a geometric object in the broader sense. One advantage of the *„?"-technique* is the intuitive, deep-seated meaning of the question mark "?". In addition it is easily manageable as only one additional symbol is needed to depict uncertainty. Changing the display from certain to uncertain (or vice versa) is very simple by adding/removing the "?"-symbol. The drawbacks are as follows: Every "?" is represented with the same size, color, value, texture and orientation as the corresponding tactical symbol, and therefore provides little visual discriminability between uncertain versus certain information. Furthermore, the usage of an additional symbol to mark uncertainty results in an overall short-term memory load of two chunks.

3.2 Impractical techniques

As explained above, the situation map is supposed to give an overview of the emergency situation as a whole at a glance. This is not possible for the techniques listed under the terms of *indirect*, *direct dynamic* and *direct static separate* in the tree hierarchy. Using a threshold for displaying binary uncertainty results in showing either only the certain or all information. Therefore, identifying the uncertain information requires comparing both displayed states, which results in an unacceptable cognitive load. Similarly, the dynamic techniques would show the uncertainty of an information over some period of time, which also prevents to grasp the situation at any time as a whole at a glance. A side-by-side representation would show the information in one situation map, the corresponding uncertainties in another, which is also unacceptable.
The *intrinsic* techniques provide the advantage of occupying only one chunk in the short-term memory. Also, showing the corresponding uncertainty of an operational information by modifying in the tactical symbol itself, there will be less occlusion of the base map. The variables position, color, orientation and shape are already used in the representation of the symbols and thus not free for displaying uncertainty. Unfortunately, using value, saturation or blurring is also not suitable in our application. Manipulating these variables to display uncertainty we found, that the conspicuousness of the symbol against the background of a topographical map is too weak. As the intensity of a stimulus is inverse to the processing time of the perceptual processor, the time for decoding the symbol will increase.

3.3 New proposals

Two intrinsic techniques turned out to be appropriate: size and texture/grain. The conceived version of the variable size displays uncertain information with a thinner line *(thin-line-technique*, see Table 1, middle). The version of the variable texture/grain displays uncertain information with a dotted line (*dotted-line-technique*, see Table 1, right resp. Figure 3). Advantages for both techniques are primarily the short-term memory load of only one chunk. The concept of uncertainty is intuitively confirmed, because the uncertain symbols consist of fewer pixels than the certain ones. As the manipulation of a symbol in order to show uncertainty does not change its major representational properties (same shape, color, opacity), the original symbol is still easy identifiable. Difficulties in using the new techniques exist because of the representational properties of the base map. Thus it could be difficult to choose an appropriate line thickness because there are already many different thicknesses used in the base map. In the case of the *dotted-line-technique* it could be difficult to get sufficient conspicuousness against a dotted background.

Original Certain Symbol	Uncertain Symbols		
	„?“-technique	thin-line	dotted-line

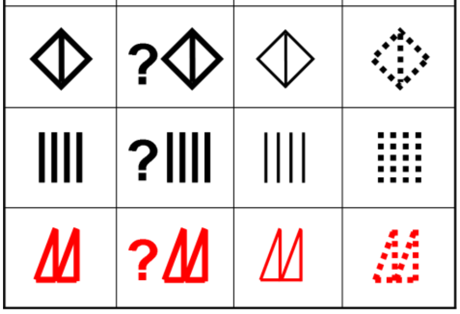

Table 1: Symbol examples showing different shapes for uncertainty

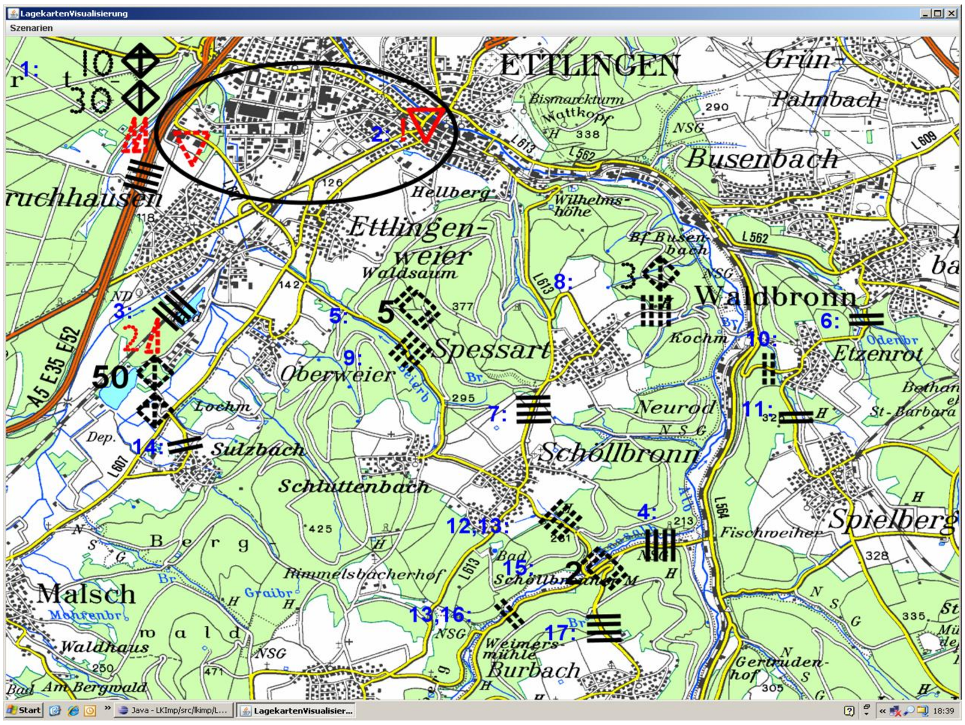

Figure 3: The scenario introduced in Figure 1, now using the *dotted-line-technique*

4. Experiments

To complement our theoretical reasoning we carried out an experimental evaluation. We enlisted seven persons to act as participants, two of them professional fire-fighters, which are familiar with the *„?“-technique* as uncertainty representation technique. Their task was to count the numbers of uncertain and certain information shown in a situation map. We measured their performance using the following formula **[7]**:

Performance = #correctly counted symbols / time

The trial was conducted using the horizontal tabletop display of IITB's Digital Map Surface, a team workplace designed (also) to be used by emergency staff **[8]** in both mobile and stationary emergency operation centers.

The result of the experimental evaluation is shown in Table 2. The order of the "test runs" was analogous to the order of the columns ("?" – "dotted" – "thin"). One striking result is that the *dotted-line-technique* comes out with the best performance results. Notably, even the fire-fighters achieve the worst results with the *„?"-technique*. We attribute the outcome of the evaluation to the unequal chunk load of the techniques.

In our future work, we intend to underpin our results by increasing the data base and by refining the configuration of the experiment in order to suppress learning effects.

proband	?-technique	dotted line	thin line
1	0,74	**1,11**	1,06
2	0,89	1,27	**1,67**
3	0,33	**0,73**	0,48
4	0,33	**0,48**	0,39
5	0,53	**0,91**	0,65
6 (FF)	0,37	**0,73**	0,48
7 (FF)	0,57	0,63	**0,64**
mean value	0,54	**0,84**	0,76

Table 2: Evaluation Results; FF = Fire-Fighters (incident commanders)

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