INFORMATION MINING FOR DISASTER MANAGEMENT

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Commission IV, WG IV/3

KEY WORDS: Disaster Management, Data Modelling, Automation, Knowledge Base, Contextual

ABSTRACT:

Within the domain of disaster management, visualisation of geo-related information in situation maps is elementary. The data acquisition for these maps is based on hundreds of written messages containing up-to-date information from damage sites. The approach and experience of a human operator used for processing these messages has to be put into practice for automation. In this paper an existing data model of the military domain is analysed. With regard to the requirements of disaster management the data model has been adapted to create an ontology supported knowledge base. For a comprehensive interpretation of the message contents, context helps to grasp the whole situation.

1. INTRODUCTION

During the management of disasters and the prevention of further hazards by *emergency operation centres (EOC)*, up-to-date information is essential for decision making. This information is based on hundreds of written situation reports, given by several on-site units and passer-by. The structure of an EOC depends on the type and extent of the diverse disaster situations. However, they all apply the same principles for information sharing. This knowledge sharing is made possible by the situation map, a representation of the current and global state of damage events based on all messages. The variety of incoming reports has to be analysed by a single operator of the management staff. This data mining process includes an assessment of the content, which is done with the help of semantic considerations, heuristic assumptions and by using context knowledge.

Aim of the presented work is to automate this process in order to assist the human operator. This paper focuses on modelling of information and processing of context knowledge based on textual reports in German language. Discussions of possible visualisation models as well as an overview about vagueness within the reports are given by Werder et. al (2006).

1.1 Conception of the SOKRATES Prototype

SOKRATES has been developed for integration in military command and control (C2) systems by the Forschungsgesellschaft für Angewandte Naturwissenschaften (FGAN). The prototype displays troop movements in a tactical map based on interpretation of military reports. These reports largely consist of free form text which has to be processed in order to produce an up-to-date map of the on-site situation. There are some striking similarities between the objectives of SOKRATES and the disaster management application (cf. Werder et. al, 2006).

The SOKRATES workflow is essentially based on several processing steps. The first step is pre-processing, which is initialized by sentence recognition. Subsequently the relevant information from the messages is transformed into a formal structure by the information extraction component, discussed in more detail in chapter 1.2. In the semantic augmentation component the structured information is enriched with the ontology supported knowledge base. In particular supplementary information like spatial references or potential dangers is added. Within post-processing the information is finally represented in the situation map. The architecture of SOKRATES is described in detail by Schade (2004).

For the integration of SOKRATES components for application in disaster management, many adaptations have to be carried out. This arises from divergent tactical symbols, domain specific jargon, differing databases and stricter regulations of military reports.

1.2 Information Extraction Components

In general, *information extraction (IE)* can be seen as a kind of data retrieval from a domain specific source. Especially textual representations, like messages in the disaster management domain, serve as input source for IE. Systems that perform IE have to be able to “find and link relevant information while ignoring extraneous and irrelevant information” (Cowie and Lehnert, 1996). What relevant information means has to be defined before processing, by extracting rules and creating a domain specific lexicon. Thereby it is necessary to define the rules as detailed as possible, in order to provide an accurate and result-oriented extraction by a minimal syntax analysis (cf. Cowie and Lehnert, 1996).

The information extraction component of SOKRATES is based on the *Saarbrücker Message Extraction System (SMES).* The SMES has been developed by the German Research Centre for Artificial Intelligence (DFKI) and is especially designed for the requirements of German language (Neumann et. al, 1997). This

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tool will also be adapted for application in the disaster management domain.

For extracting relevant information, the SMES has to be enlarged and modified regarding the lexicon and the transducers. The responsibility of this lexicon is to denominate possible unit types, events and locations. In order to be able to classify locations, all street names, towns and points of interest have to be integrated into the lexicon. Furthermore the important terms for describing damage states have to be added, like the states of a fire. The finite-state transducers, which are used by the SMES, represent a framework for syntactic analysis of language. Transducers assign a domain specific function to each term. They extract information into *typed feature structures*, which is a standard formalism in computational linguistics (cf. Pollard and Sag, 1994). The important role of the typed feature structures is to provide information for padding the ontology. The architecture of the IE within SOKRATES as well as application scenarios are described in detail by Hecking (2004).

2. DISASTER MANAGEMENT ONTOLOGY

The extracted information from each message adds additional knowledge to the situation picture. In order to represent this knowledge formally an ontology is used. According to Gruber (1993) the term ontology is defined as “an explicit specification of a conceptualization”. Because it is impossible to specify knowledge completely, an ontology is always restricted to a set of objects that it is able to represent, the so-called *universe of discourse*. These objects are defined in an ontology by classes and the relationships between them. A human-readable textual description of both, along with rules that constrain interpretation and usage of objects, finally add meaning to the ontology.

In the following the ontology of the military domain along with the adaptation of this ontology for the disaster management domain are presented in more detail.

2.1 The Command and Control Information Exchange Data Model (C2IEDM)

Sharing information is an important aspect of multinational, combined and joint military operations. In modern armies Command and Control Information Systems (C2IS) are used to manage own forces and to obtain situational awareness. The Multilateral Interoperability Programme (MIP), an association of 24 nations and several organisations, developed the *Command and Control Information Exchange Data Model (C2IEDM)* to define the information exchange between different C2IS. The minimum requirement demanded by the MIP is that the “meaning and relationships of the information to be exchanged” (C2IEDM, 2005) need to be preserved.

The C2IEDM ontology defines a total of 194 entities in its logical data model. From these only 15 are independent, which means that their identification does not depend on any other entity. The independent entities provide an overview of the data model (see Figure 1).

The intensely connected entities *Object-Type* and *Object-Item* are both used to model a particular object in the C2IEDM. *Object-Type* defines the attributes which values are common among all objects of a particular type (e.g. fuel capacity in litre of a vehicle type). In contrast, the entity *Object-Item* defines the attributes which values can differ between all objects of a particular type (e.g. hull number of a vehicle). At the top level of their hierarchies the object entities define five different subtypes that can be modelled in the C2IEDM – *Facility* (e.g. airfield, road), *Feature* (meteorological, geographic and control features), *Material* (consumable material and equipment), *Organisation* (administrative and functional) and *Person*.

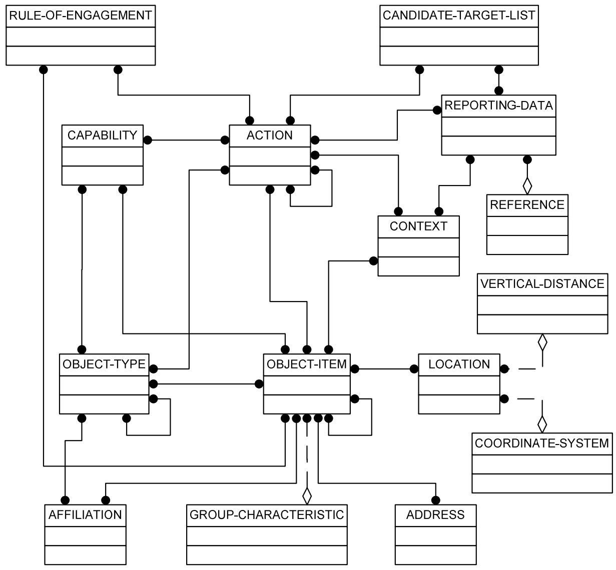

Figure 1. Independent entities of the C2IEDM (C2IEDM, 2005)

Spatial reference is summarized in the entity *Location* and is based on the definition of both absolute and relative points. The geometry of an object can be defined by a point, line, surface, geometric volume or by their respective subtypes (e.g. surface can be a corridor, polygon, polyarc, fan, track, orbit, or an ellipse). Relative points hereby permit positioning of objects relative to other objects as well as a simplified specification of geometries by the use of Cartesian offsets. The geographical reference is set by the definition of absolute points. Their coordinates are defined by latitude and longitude in the World Geodetic System 1984 (WGS 84) along with their vertical distance. The entity *Address* is not related to *Location* in the data model because it is only used for communication purposes. It is either an electronic address, accessible via a network service, or a physical one, reachable e.g. via postal services.

In the C2IEDM activity is represented by the entity *Action*. Planned and carried out activities as part of military operations are covered by *Action-Task*. In contrast, activities whose plan is unknown are covered by the entity *Action-Event*.

Information about the changing situation is stored directly in the corresponding entities of the data model. Subsequently the entity *Reporting-Data* is linked to these entities and provides amplifying data such as source, quality and timing. If the information is gathered from external sources, e.g. from a telephone conversation, the entity *Reference* can be used to provide metadata for the reported information.

The entity *Context* is in the terms of the C2IEDM a “collection of information that provides in its entirety the circumstances, conditions, environment, or perspective for a situation” (C2IEDM, 2005). *Context* therefore bundles only information that is already available and is in many cases limited to collecting instances of *Reporting-Data* under a single label. It can also provide amplifying information for an *Object-Item*, e.g. hostile units that are approaching to the object's position. Additionally *Context* can be used to specify the prerequisites and estimated results of an *Action*.

The other independent entities of the C2IEDM shown in Figure 1 are less important for the adaptation and will not be discussed here.

2.2 The Disaster Management Data Model (DM²)

The *Disaster Management Data Model (DM²)* has been developed for an application in disaster management based on the C2IEDM. The data model does not cover all facets, e.g. resource management is not considered in detail yet. Nevertheless, many considerations concerning the DM² apply to ontologies in the domain of disaster management in general.

The most important entities of the DM² are shown in Figure 2 and the differences and new concepts in comparison to the C2IEDM are discussed in the following.

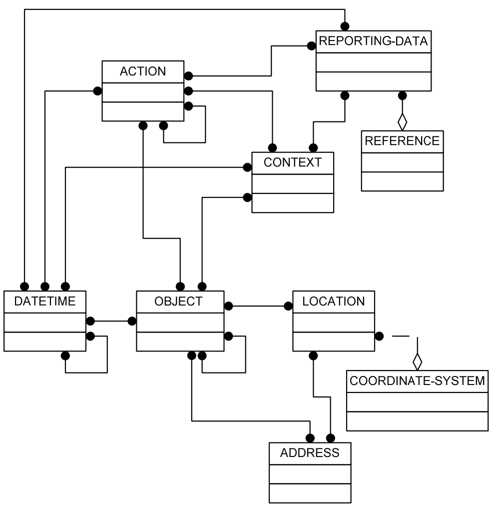

Figure 2. Important entities of the DM²

In contrast to the C2IEDM, which has been designed for information exchange, the DM² has been designed for serving as a knowledge base, so information storage, retrieval, and processing play an important role. For an easier usage in object-oriented programming languages, the disaster management ontology is modelled in terms of inheritance. The most obvious change is the unification of the two entities *Object-Type* and *Object-Item* into a single entity, which reduces some overhead.

The universe of discourse of the disaster management differs from the military one; therefore several changes had to be applied to the subtypes of the objects. To *Facility* the concept of buildings including their role (e.g. school), crossings and squares were added. The entity *Feature* was enhanced to handle administrative structures (e.g. district, town), damage sites, operation sections and standby areas. *Material* was renamed to the more common term *Resources* and holds the resource hierarchy. This depends on the actual conditions, because e.g. the actual fleet of vehicles differs from country to country. *Organisation* and *Person* were also adapted to the circumstances of disaster management, e.g. emergency operation centres were added. Objects can be set as part of an object hierarchy, e.g. all districts are subordinated to the corresponding town.

The DM² also differences between planned and unplanned activities. The subclass *Action-Task* has been extended by the tasks of disaster management, like fire fighting. *Action-Event* covers several disasters types in the C2IEDM, but for disaster response several additional attributes describing the nature of disasters are needed. These were introduced to the DM², e.g. for an earthquake the location of its hypocenter and magnitude are of significant importance for the decision making process.

Written report forms used in disaster management often provide a field to indicate the priority of the message. The terms and graduations that are used differ. The Common Alerting Protocol (CAP, 2005) provides a field called "urgency" with five levels that denote the available response time. In the DM² the four priority levels from the German standard DV 810 (1977) were introduced to the entity *Reporting-Data*.

Defining geometries is elaborated in detail by the *Location* entity of the C2IEDM. Nevertheless, the DM² uses only a subset of the possible geometry types. For the situation map only two dimensional geometries are needed and special surface subtypes like corridor are normally not used for describing disaster events. Additionally the concept for setting the geographical reference of objects and geometries had to be adapted. The restriction of the C2IEDM to coordinates defined in WGS 84 is too strict for application in disaster management, because in many cases the geographic information used as a basis for disaster response is available only in other coordinate systems. The DM² therefore permits the usage of another reference frame than the WGS 84. Nevertheless the DM² is restricted to a single reference frame, in order to avoid negative side effects due to inhomogeneous coordinate definitions.

The impacts of disasters depend on several aspects. One aspect is their location, e.g. in densely inhabited areas the damages and risks are often more severe. In urban areas buildings play an important role – they can be affected by disasters but they can also be used during disaster response, e.g. as gathering places for homeless people. Because in free form text the location of a building is normally given by its address, in the DM² the entities *Address* and *Location* are associated. The translation between the two entities can be performed by a simple geocoder as part of the augmentation component.

Concerning the practical implementation of the system and the transfer of the logical data model to a physical data model several aspects have to be considered. Because the DM² serves as a knowledge base, all relevant information can be aggregated in a database system. This information includes the geospatial data, e.g. the topographic information. For the processing step of semantic augmentation geo-related computations are often necessary, e.g. obtaining the distance between a damage site and nearby high risk buildings. For these computations either an embeddable GIS component or geospatial database functions can be used.

In ontologies associations between entities are of crucial importance. Regarding the DM² this is especially the case for the association entities that capture the highly dynamic situation in terms of time (*DateTime*), geometry and geographical reference (*Location*) and changing attribute values (*Status*). The principles behind this concept can be best shown by the association entities connecting the *Object* entity in the DM² (see

Figure 3). An individual object can move, so tuples with (*Object*, *DateTime*, *Location*) track the position in *Object-Location*. Also some parameters of an object can change over time, e.g. the availability of units. Therefore these values are tracked in tuples (*Object*, *DateTime*, *Attributes describing the status*) in *Object-Status*. But tracking is not only important for units but also for the position and extent of damages, e.g. fires or flooded areas. Because the affected area of an event is not restricted to facilities but can also be of feature type, flexible tracking of events is possible.

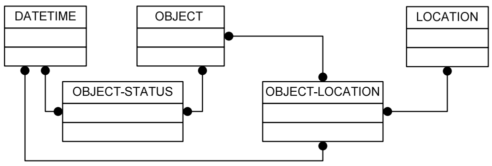

Figure 3. Associations of *Object*, *DateTime* and *Location*

Context in the DM² is no longer an exclusive collection of already available data as it is in the C2IEDM – it can be used for evaluation of information as well as for the inference of new information, as shown in the following chapter.

3. CONTEXT – A FUSION OF CONTENT

The importance of context is well-defined within the use of language. An isolated word refers to a denotation but is still meaningless. Thus, it is the context of the sentence which adds the meaning. Context is not necessarily restricted to language since this principle is similar in diverse disciplines. Processing isolated pixels within image analysis is as almost impossible as the interpretation of an individual report in the domain of disaster management. These reports are based on impressions and individual observations of one-site units. Also, the knowledge level of the messages depends on the source and the type of observation. As a consequence of the free text form, fuzziness of the content is inherent in the messages. Furthermore, vagueness is included whenever the author expresses assumptions. According to these different aspects, reports represent a generalised description of the situation in diverse abstraction levels. So-called *semantic gaps* are a conceptual summary of these facets.

During processing and analysis of incoming messages, human operators instinctively create references between different reports and organize these depending on the content. This type of semantic enrichment is based on the usage of context knowledge, which is evolved by the multitude of reports. For an automatic application in disaster management, the usage of context knowledge in the message analysis has to be adapted from human approaches. Content dependent fusion of diverse messages offers an elegant solution. For detecting these similar and significant content structures, methods of information technology are necessary.

Such methods are a kind of *data mining* because of the process-oriented detection of significant structures in a dataset (Bensberg 2001). Contrary to a number of publications, Bensberg emphasizes the importance of structures. Hence the limitation to large amounts of data is secondary for their processing.

3.1 Context in the Disaster Management Data Model

Within the DM² context is a powerful instrument for semantic enrichment. The implementation is related to the C2IEDM, by the direct cross linking of the main entities *Action*, *Object*, *DateTime* and *Reporting-Data* (cf. Figure 2). By this approach the essential information is concentrated in association to a single entity. Additional information, like the geographical position, is already given inherently by the enlisted objects.

Nevertheless, the philosophy behind the context differs as the context in the DM² is organized task-related. Thus the main context of a disaster is subdivided into three separate types of contexts providing three complementary perspectives on the aggregated information. The first context *Action-Context* is focused on the relations between the diverse actions and their dependences. Thus it becomes possible to model e.g. injured people in consequence of a fire. The *Feature-Context* is focused on the coherences of objects, actions and time. In this manner individual objects like an organizational unit or individual actions like a burning facility are represented as a whole situation including the temporal references. The third type of context, the *Reference-Context*, relates the reported facts of a message to each other. That way the facts of a report are bundled and relate to the same attributes. Following this approach a multitude of either-way independent, crossed or coincided context-entries arise.

According to this method, it becomes possible to identify and detect all coherences within the ontology for semantic enrichment.

3.2 Processing Context Knowledge

The discussed ontology offers the possibility to link different facts case related in different types of context. However, the types of context should be identified as automatically as possible for a set of data. Thus the processing of context starts with the “least common denominator” of the reports.

For finding this “least common denominator” the course of messages representing the chronology of a disaster has to be considered. In the first phase of a disaster the incoming messages show common characteristics, which are quite simple. Normally, the messages include indications for a disaster along with the source of information and a location. In this manner the disaster location offers the first reference for further processing and the basis for creating each type of context. These considerations are quite similar to the approach of a human operator.

The definition of “the same location” for creating context is possible by the introduction of a so-called *event horizon*. The event horizon is the sphere of influence of a reported fact and its shape and size depend on the meaning of the content. The sphere of influence in this application is a buffer, individually defined for each type of reported fact. That way the sphere of influence of a derailment is much smaller than the sphere of influence of smoke, which can be seen and smelled over a long distance. According to that approach, reported facts are related whenever their event horizons overlap. Thereby it is important not to confound the “virtual” sphere of influence of the reported fact with the fact itself.

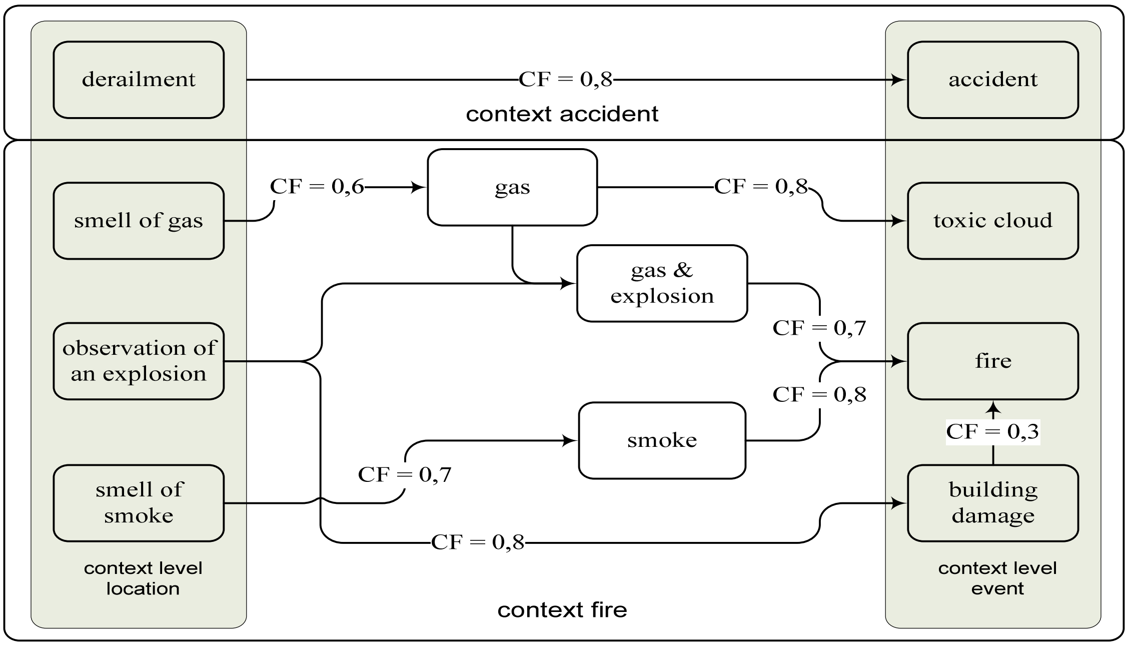

Figure 4. Inference net including the certainty factors and the levels of context

The location context offers the possibility for a new kind of interpretation of message content. Similar locations, in the meaning of overlapping event horizons, which are mentioned in various reports, establish the first evidence for a particular disaster, a so-called *hypothesis*. Conditions respectively restrictions for matching diverse types of facts to the same context have to be defined. The inference nets from the knowledge based diagnose system *MYCIN* offer a solution for this problem, presented in the following (Beierle and Kern-Isberner, 2006).

MYCIN (cf. Buchanan and Shortliffe, 1984) is one of the first knowledge based expert systems designed for processing and representation of uncertain knowledge. MYCIN has been developed since 1972 by the University of Stanford for diagnosing different diseases in dependence to the different symptoms. Modelling these coherences is made possible by defining conditions and relations of different evidences. These basic relations are "if A then B", "A and B" and "A or B". This assortment of relations is quite simple, however similar to the approach of a human operator. Additionally the relation "if A then B" is complemented by a *certainty factor (CF)* for implementing a weighting as shown in Equation 1.

$$A \xrightarrow{CF(A \to B)} B \tag{1}$$

This equation expresses the degree of belief of the conclusion B if the premise of A is true. Thereby it is important not to confound the degree of belief and the probability for B on the condition of A. The confidence region for the CF is given by the interval [-1, 1] $\in \mathbb{R}$. The meaning of this range is [-1 ≡ confutes], [0 ≡ neutrally] and [1 ≡ confirmed]. In this manner it is possible to model evidences for and against a *hypothesis*.

CF [B] represents the *cumulative certainty factor* with dependence to the "rule base" (A→B) and the *evidence* (in this case represented by *CF [A]*). So the cumulative certainty factor exists for the *evidence* as well as the *hypothesis.* This serial combination is shown in Equation 2.

$$CF[B] := CF[B, \{A\}] = CF(A \to B) * \max\{0, CF[A]\} \qquad (2)^*$$

For processing context, the propagation rules for the conjunction and disjunction are represented by Equation 3. These equations make the empiric definition of the relations "A and B" and "A or B" possible. In this manner the interaction between different *evidences* to a *hypothesis* can be balanced.

$$\begin{aligned} CF[B, \{A \wedge B\}] &= \min\{CF[A], CF[B]\} \\ CF[B, \{A \vee B\}] &= \max\{CF[A], CF[B]\} \end{aligned} \qquad (3)^*$$

The final case for modelling is the parallel combination of *evidences*. This is necessary whenever different *evidences* link to the same *hypothesis*. Equation 4 represents the mathematical interpretation of this case.

$$CF[B, \{A_1, ..., A_n\}] = f\left(CF[B, \{A_1, ..., A_{n-1}\}], CF[B, \{A_n\}]\right) \quad (4)^*$$

With these equations the different reports can be processed and matched to the different types of context. This procedure is illustrated by an example, in which the initial situation is given by four reports with the content of derailment, smell of gas, observation of an explosion and smell of smoke. The messages comply with the basic condition of overlapping event horizons, because of "the same location" of the reported facts. That is why they are contained in a common location context (cf. Figure 4).

The spatial information needed for this analysis is given by sender's explanations, like: "I have seen an explosion at the ARAL petrol station". The location given in this report is the distinctive ARAL petrol station which has to be part of the DM² database. The reported fact is the observation of an explosion.

Processing these messages creates possible *Action-Events* and defines also the specific event contexts. The report about observation of an explosion is an evidence for the *hypothesis* of

[*] (Beierle and Kern-Isberner, 2006)

building damage. The degree of belief for this *hypothesis* is [0,8] and results from Equation 2. On the other hand the same content from the observation of the explosion creates in combination with the *evidence* of gas a new *evidence* for the *hypothesis* fire. This conjunction can be modelled by Equation 3. Also, the *hypothesis* fire is a parallel combination of the *evidence* gas & explosion, smoke and building damage. This dependence is described by Equation 4.

For the creation of context, the dependencies between *evidences* are important. When *evidences* depend on each other, they create a common context. Following this rule, the context of fire is created by joining the content of the three dependent messages. By contrast the contexts of independent *evidences* are generally incompatible. In the example (Figure 4) this can be seen concerning the report content of the derailment, which does not fit the context of fire. The evidence of the derailment uniquely links to the *hypothesis* of accident. According to that link, the context of accident arises and includes the derailment report by a reverse processing. So the context of fire and the context of accident can be seen as independent.

hypothesis	accident	toxic cloud	fire	building damage
belief	[0,90]	[0,48]	[0,91]	[0,80]

Table 5. Degree of belief for the *hypotheses* of *Action-Events*

The cumulative certainty factor shows the degree of belief for a *hypothesis*. This is important whenever the *evidences* provide different *hypotheses*. Within the example (Figure 4) the *evidences* smell of gas, observation of an explosion and smell of smoke lead to the *hypotheses* of toxic cloud, fire and building damage. On the basis of the belief shown in Table 5, the decision can be made in favour of the *hypothesis* fire.

CONCLUSION

A specific application of "automated geo-spatial data acquisition and mapping" offers the transformation of verbally given geo-information into a situation map. For a successful transformation it is essential to develop a domain specific knowledge base. The presented Disaster Management Data Model is based on the Command and Control Information Exchange Data Model. Although the C2IEDM is a sophisticated standard, the DM² points out important considerations that have to be taken into account for disaster management ontologies in general.

The semantic of the reports, which is given by the use of context, plays an important role for the transformation. The first common context level is defined by the spatial reference of the reports. Starting from the context level of location, it is possible to develop the domain context.

The future research focus is on uncertainty and reliability, which has not been covered by the SOKRATES system yet. These are different facets of messages in the disaster management domain. Uncertainties exist concerning the location, the dimension and the quantity. Considerations of reliability, resulting from message source as well as adverbial phrases like "probably", "presumably" or "perhaps", have to be integrated. A possible solution for this problem is also seen in the usage of context knowledge.

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ACKNOWLEDGEMENTS

The presented work has been funded by the Deutsche Forschungsgemeinschaft (DFG), project no. BA 686/16 "Abstraction of Graphically and Verbally Represented Geoinformation" (Christian Lucas) and as part of the Collaborative Research Center (CRC) 461 "Strong Earthquakes: a Challenge for Geosciences and Civil Engineering" (Stefan Werder).