

EXPLORING ONTOLOGY POTENTIAL IN EMERGENCY MANAGEMENT

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ABSTRACT:

Emergency response is a complex activity involving many actors and heterogeneous spatial data. One of the major challenges is the integration and understanding of these data by all the actors. While quite significant progress on system and syntax heterogeneity of data has been made, semantics issues are still insufficiently addressed. This paper discusses the possibility for applying ontology to resolve the semantic heterogeneity in emergency response. The paper introduces the interoperability problem by presenting a case study. Then, the basic ontology technology is introduced and discussed with respect to the emergency response processes. Finally, we present our concept on how to realize the semantic interoperability in emergency management.

1 INTRODUCTION

Natural and man-made disasters have been regularly happening throughout the human history. Recent large natural (South Asia tsunami, Katrina hurricane, China earthquake) and man-made (e.g. 9/11, the attack of the London underground) have shown an increased complexity of emergency management, which requires new approaches and tools for decision-making. How to alert, response, shelter and recover from these events is a challenge to human beings and have been approached from various disciplines. First responders need to have access to all kinds of spatial data in order to figure out the rescuing methods in a short time. In large disasters, there are a countless number of people who may cooperate with each other when the disaster happens, but normally emergencies are managed by four response units, i.e. the fire brigade, police and medical services and the municipality (Xu and Zlatanova, 2007). Although dealing with the same incident or disaster, the information needed by different groups may be very diverse. For example, in case of a large forest fire, the fire brigade needs to get all the roads (paved and sand) leading to the area, while the police and ambulance would need the paved roads only. The municipality should have a clear idea of the locations of buildings and houses and the number of people inside to be able to prepare evacuations. All this information should be extracted from different data sets, processed and distributed accurately in a short time, which in turn depends on the support of data interoperability.

It is expected that Spatial Information Infrastructure (in short, SII) can help in finding and accessing existing spatial data (Scholten et al., 2008). However, SII's focusing currently only on system, syntax and structure interoperability (Sheth, 1998, van Harmelen, 2008). System interoperability deals with the data difference on hardware, operating systems, and communications, such as communication protocols. Syntax and structure interoperability covers the data difference on data representation, formatting, data models, different Data Base Management System. Semantic interoperability concerns the data difference on meanings of a language, code, message or any other form of representation (Sheth, 1998). Semantic heterogeneity of the spatial data is still one of the biggest challenge in emergency response. For example, a fire brigade may use 'house' for the same real-world feature that is

mostly recorded as 'building' in the topographic map. Since the people involved in emergency response as well as the the spatial information they use coming from different domains, the used vocabulary can be very different. Furthermore, emergency responders may submit and ask for needed information in different forms, not to mention providing them with the right information to perform their task. This makes the communication between the involved groups more complicate. Hence, how to integrate different data sets considering the human terminology is a critical issue in managing emergencies (Visser et al., 2002, van Harmelen, 2008).

There should be a unified definition on concepts, relations, restrictions, and so on, to be referred to when the computer tries to 'understand' the spatial data's meanings. This unified definition is called the standard terminology (Sheth, 1998). Many researchers suggest applying ontology to represent the standard terminology, and then resolve semantic interoperability in the work of emergency managers (Neches et al., 1991). Having the terminology for users and data unified will help in search and integration of data with respect to the task of the user.

The paper discusses the potential of using ontology in resolving semantic heterogeneity in emergency response. The paper is organized as follows: Section 2 introduces a case study of emergency management to illustrate the semantic heterogeneity in emergency management. Section 3 analyzes theoretically the possibility of applying ontology in emergency management. Section 4 introduces the basic knowledge of ontology and discusses the main steps of ontology modeling. In section 5, a dynamic data model in emergency management is introduced to analyze how to use ontology in emergency management. Finally, we conclude the article with the next step and further research in Section 6.

2 A CASE STUDY

The emergency situations could vary a lot. Each kind of disaster management would require different data sets and procedures to manage it. Here, we will concentrate on one case to illustrate the problems.

Let us imagine there is a big fire in certain urban area. The fire has started in an industrial establishment near the city and has spread over several industrial buildings. As a result of the fire, a large cloud with dangerous substances is released. In this case, the first emergency management actors are the fire brigade, the local paramedics, the police, the municipality and the advisor for dangerous substances (ADS). The tasks and the roles are clearly defined: the fire brigade trucks have to go to the locations from where they can fight the fire; the medical personnel have to take care of citizens with medical complains; the municipality have to monitor the situation and decide whether evacuation from the affected area should take place; the ADS have to assist in taking samples from different locations in the affected area and compute the plume.

Presently, there are many systems for Command and Control (in short, C&C) that can provide all the data needed by the actors, such as Eagle One (Figure 1) and MultiTeam (Figure 2). However the current systems do not distinguish between different actors and data sets. The systems access and display all the data available no matter what the task of the actor is and what the content of a specific data set is. This approach may create an information overload as well as confusion. Some of the displayed data might even be not understandable for some actors since they are coming from a different domain. The semantic heterogeneity is very high.



Figure 1: Eagle One (GEodan, ESRI, Microsoft)

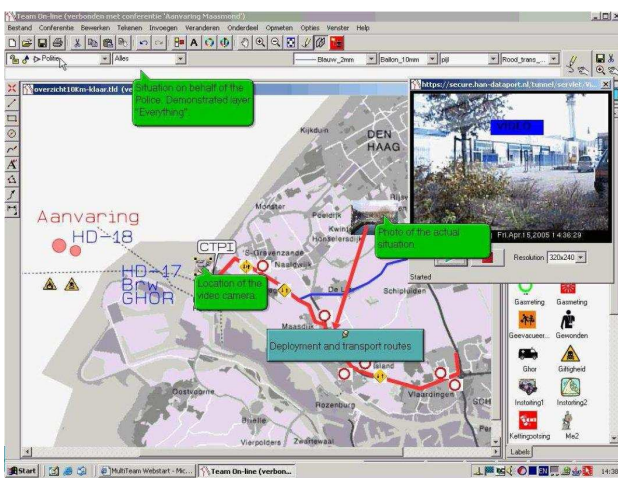


Figure 2: MultiTeam (region Rotterdam)

Figure 3 shows the information sharing between emergency management actors (municipality, policemen, fire brigade and medical center) and static data sources (CityGML, Cadaster, TOP10)

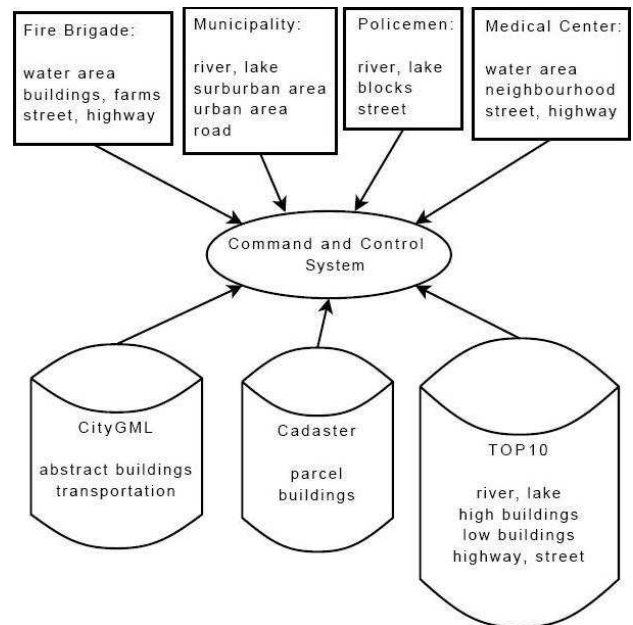


Figure 3: Information sharing in C&C system

in C&C system. However, the system could not extract the right information to the right actors, because the system does not have a specific interface, which can use the terminology of the user groups 'river, lake, water area', 'suburban area, urban area, blocks, parcel, buildings, abstract buildings, high buildings, low buildings, farms, neighbourhood' and 'road, street, highway, transportation'. The basic reason of this disadvantage is these words groups used by actors and static data sources are not 'understood' by the computer. Thus, computer could not distinguish them from each other, and then get the target information from static data sources to actors.

Facing this challenge, ontology is expected to give these words groups explicit and formal definition on their meanings. For example, 'road' in municipality's vocabulary could be defined as 'a kind of path that vehicles and pedestrians could pass', 'highway' in TOP10 could be defined as 'a kind of path only permits vehicles to pass', 'street' in TOP10 could be defined as 'a kind of path that vehicles and pedestrians could pass and usually have certain speed limit'. Based on these definitions, the computer could distinguish the 'meaning' of these three words and find the relations between them. Specifically, both 'street' and 'highway' are a kind of 'road'. 'street' is different from 'highway'. Then, the computer can acknowledge the differences of these words and get actor-needed information in TOP10 out.

3 SEMANTIC INTEROPERABILITY IN EMERGENCY MANAGEMENT

Nowadays, spatial data are stored in a large diversity of models not specifically intended for emergency response. Emergency managers want to get needed information by considering those various kinds of models before taking actions. However, mapping between emergency managers' models with these models should be built every time whenever either part of the mapped pairs is changed or a new model is needed. As ontology can define the uniform definitions for model's data, it may reduce the time and complexity of model mapping and integration so as to extract the correct information that would support the task of every actor efficiently.

Besides, fundamental operators on spatial data also requires the agreement on the meaning. There are lots of semantic information, such as, area, population, topology, can be accessed more easily by ontology method than traditional spatial method (Pundt, 2008), if their meanings are well-defined. For example, fire brigade may want to know the shortest path from their station to the disaster field. This requirement asks for path searching from the geographical data on the map. The 'shortest path' can be computed by the path topology structure on the map. However, before searching the shortest path, the meaning of 'path topology structure' should be defined. The agreements on spatial concepts' meanings are important and needed for decision makers of emergency management, since their understanding about a certain feature may differ from the way this feature is represented or modeled in a particular model. According to the example, different data models may have different topology structures. However, in the spatial data sets, real-world features, their attributes and spatial relationships are frequently modeled and stored, except their semantic meaning. Thus, ontology modeling approach may be applied on spatial data (Pundt, 2008).

Furthermore, ontology also may help in providing the context-related data to emergency actors by reasoning. On the basis of the context it can be decided whether the data is relevant or not. If the data is not relevant to the context, it is not the target information for the user in that situation no matter whether it is available in the data set. For example, in section 2's case study, the maps of the field where the fire is happening are quite useful for the emergency management actors. But, if the maps are defined their semantic information (like covering area, boundaries) by ontology, it is easy to find out whether the map is the required one or not. It could be realized by ontology reasoning on compute whether this map has semantic relationships with the context. Thus, emergency managers also want to compute the explicit relationships between objects in a spatial data situation (Pundt, 2008), which could be achieved by ontology reasoning.

4 ONTOLOGY

Ontology is a word in philosophy, which stands for 'the philosophical study of the nature of being, existence or reality in general, as well as of the basic categories of being and their relations'. Researchers of computer science imported this word and defined a brand new definition. In theory, ontology is defined as 'an explicit and formal specification of a conceptualization' (Gruber, 1993). There are two important aspects in this definition:

1. Explicit: Each concept's meaning is defined clearly and uniquely.
2. Formal: The concepts in the ontology is defined by the well-defined language so that machines could understand easily.

There are many relationships in ontology that link different concepts together into a big concept network, which also helps the machine to search through the created knowledge. (Antoniou and van Harmelen, 2004). In one word, ontology is a network of concepts and relationships, which provides specifications of the knowledge in the world people are working on (Uschold and Grüninger, 1996). As a key technology in semantic field, ontology is a unified structure which can not only act as a conceptualization but also be shared. It is a standard explanation of concepts and relations used by the system (Agarwal, 2005, Visser et al., 2002, Bittner et al., 2005). Moreover, ontology reasoning can help find out the implicit or contradicting relationships that can hardly be discovered by human being.

Above all, we think ontology may help resolve the semantic heterogeneity problem in emergency management. The explicit and formal definition of each concept helps the C&C system share the information with different emergency actors, and update, search context-related information to the actors with high accuracy.

4.1 Ontology Modeling

Given the definition of ontology, then in this section we are going to illustrate how to build the ontology. The main steps of building ontology are three: ontology capture, ontology coding and ontology mapping (Uschold and Grüninger, 1996).

In general, there are various kinds of ontology can be built (Agarwal, 2005).

1. Knowledge Representation Ontology: It defines the representation primitives in formal language.
2. General Ontology: It defines the vocabulary concerning with things, events, time, space, etc.
3. Meta-ontology: It defines the knowledge beyond the domains.
4. Domain Ontology: It defines the concept and relationship of a certain application domain.
5. Reference Ontology: It defines the top-level concepts and relationships for the negotiation on meanings across different domains.
6. Linguistic Ontology: It defines the natural language or grammatical concepts to link the philosophical ontologies with engineering ontologies.

4.1.1 Ontology Capture In this step, key concepts and relations in the knowledge field should be picked out. The definition of the concepts and relations should be specified. Usually, key concepts and relations are decided depending on the aim of the ontology. If the ontology is to provide a knowledge classification for the application field, several concept classes are chosen. If the ontology is to link oral words with the abstract concept, perhaps a linguistic ontology is needed.

In the case study of section 2, the ontology capture step could be realized as follows. The key concepts are 'transportation, water area, suburban area, urban area', which could be treated as four main classes of the scenario. Then, the trivial and detail concepts can be added into these four classes. Such as, 'road' is a subclass of 'transportation'. 'Highway' is a subclass of 'road', for it only permits vehicles pass. 'Street' is also a subclass of 'road', which have speed limit. Similarly, 'lake, river' are subclasses of 'water area'. 'Neighbourhood' is the subclass of 'urban area'. 'High buildings', 'low buildings' and 'abstract buildings' are both subclasses of 'buildings'.

After classifying all the concepts into the main classes, relationships between them should be specified. Such as, 'urban area' is made up of 'water area, blocks, buildings, road, parcel'. 'suburban area' is made up of 'water area, farms, buildings, road, parcel'.

4.1.2 Ontology Coding In this step, ontology is written in chosen ontology language according to the definitions of concepts and relationships agreed in ontology capture step. The commonly used ontology language are OWL (Web Ontology Language, <http://www.w3.org/TR/owl-features/>) and RDF (Resource Description Framework, <http://www.w3.org/TR/rdf-primer/>). Ontology editor are Protégé (<http://protege.stanford.edu/>) and KAON2 (<http://kaon2.semanticweb.org/>). Ontology Reasoner are RACER

(Haarslev and Moller, 2003), FaCT++ (<http://owl.man.ac.uk/factplus/>) and Pellet (<http://pellet.owldl.com/>).

The paper (Wache et al., 2001) introduces three kinds of ontology architecture for information sharing: global ontology architecture, peer-to-peer ontology architecture and hybrid ontology architecture.

1. Global ontology architecture: there is only one big ontology for the application field. All concepts and relations are well-defined by ontology without referring to other ontologies. This architecture is suitable for the application case that all parties of this application domain have a common understanding and agreement on the concepts and relations within the application domain.
2. Peer-to-peer ontology architecture: in this architecture, there are several ontologies. Furthermore, there are mappings between them. Ontology designers should find out the corresponding concepts or relations of one ontology from another ontology of this architecture in order to link them with each other. Finally, these ontologies could also form a concept and relation network as the global ontology architecture. But it could be foreseen that many redundant data may exist in this architecture, and it also cost a lot of time to build this network. Because this architecture has less constraint on the parties' agreement on concept and relations of different ontologies.
3. Hybrid ontology architecture: this architecture is the compound structure of the above two. In this architecture, a general ontology is build for the shared vocabulary of each individual ontologies. A commonly agreed definition and constraints of shared vocabulary are defined in the general ontology.

Usually the hybrid architecture is preferred. In the case study in section 2, it may build a domain ontology, which have main classes of 'transportation, water area, suburban area, urban area'. Each actor and static data source will also build their own ontologies. Then, the mapping between each individual ontology and the domain ontology should be established after each ontology is built.

4.1.3 Ontology Mapping Usually more than one ontology are built, so this step is going to build the mapping between different ontologies for later information sharing.

Current development of ontology mapping derives from various research areas. But concisely speaking, there are four main methods being used: linguistic method, statistical method, structural method and logical method (van Harmelen, 2008). Linguistic methods build the mappings by finding the similarity from attached labels of source and target concepts. Statistical methods build the mappings by matching concepts' instances. Structural methods build the mappings by finding out the relationship between two concepts according to their locations in their ontologies. Logical methods build the mapping by computing the logic relations between source and target concepts.

In the case, when mapping the municipality's ontology with TOP10's ontology, linguistic method may be used to map the concepts 'river, lake' in both ontologies. Statistical method may be used when concept 'road' in municipality's ontology with concepts 'street, highway' in TOP10's ontology. Concept 'road' will certainly contains the instances of 'street, highway'. Therefore, the latter are the subclasses of 'road'. Structural method could be also used on mapping 'road' in municipality's ontology with 'street,

highway' in the ontology of TOP10. In municipality's ontology, 'road' is part of 'urban area'. In contrast, in Medical Center's ontology, 'street, highway' are also part of 'neighbourhood'. Moreover, 'neighbourhood' is the subclass of 'urban area'. Then, 'road' and 'street, highway' must have certain relationships of generalization. Logical method could be used to map concept 'transportation' and concept 'road'. 'Road' is 'transportation' on land. That is to say, 'road' has the definition by attaching a restriction on definition of 'transportation'. Then, logically speaking, concept 'transportation' subsumes concept 'road'. Therefore, 'road' is the superclass of 'street'.

5 ONTOLOGY MODELING FOR EMERGENCY MANAGEMENT

All the above illustration only focuses on static data used in emergency management. Actually, apart from static data, many dynamic data also being used in emergency management. Dynamic data is the data gained after the disaster happens, which is not originated from database built before the disaster, but from the region server of the disaster spot. In this section, we are going to illustrate how to realize ontology modeling for dynamic data in emergency management.

Figure 4 shows the dynamic data model of Emergency Management described in UML (Dilo and Zlatanova, 2008). In this figure, only main classes and their associations are shown. Multiplicities of the associations are shown if it is not 1. Dashed lines indicate the dependency, which means the source data only exists depending on the target data.

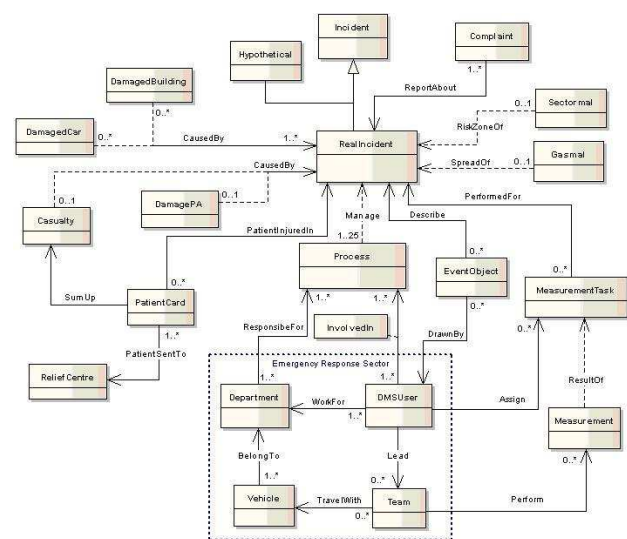


Figure 4: Conceptual model of dynamic data for emergency response

When the disaster happens, buildings and cars are destroyed. People and animals are hurt. Those four kinds of damaged information are contained in the classes 'DamagedBuilding', 'DamagedCar' and 'DamagePA' respectively. Then, complaints from people are reported on the disaster field, which is contained in the class 'Complaint'. In such condition, several predefined processes are activated to save people out and deal with the disaster in order to reduce the property and life loss, which is contained in the class 'Process'. Class 'EventObject' contains the event information that happened in the disaster field. Four main classes, 'Department', 'DMSUser', 'Vehicle' and 'Team' are emergency response sector. 'DMSUser' and 'Team' are both in charge of

measuring the information of incident if it involves dangerous substances. In such case, ‘Sectoral’ and ‘Gasmal’ contains the information on the affected area and gas plume. We build this UML conceptual model into ontology by Protégé, which is shown in figure 5.

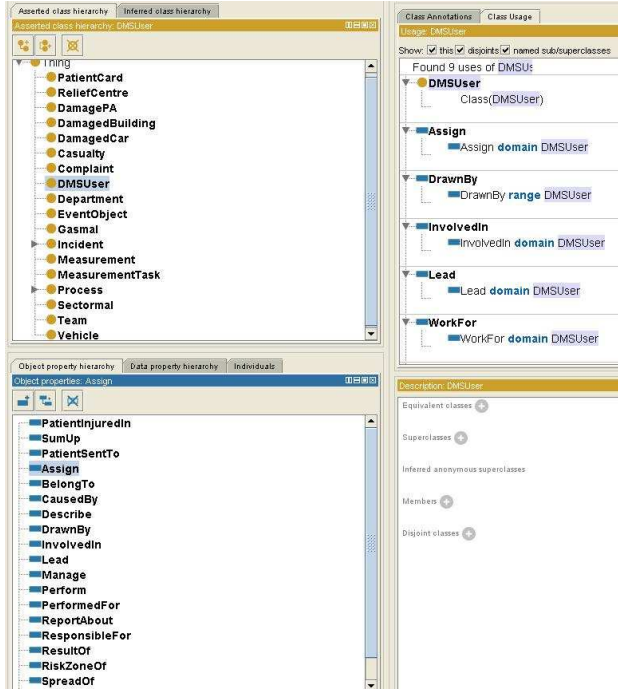


Figure 5: Ontology of the dynamic data model

However, from this ontology, many semantic information are still not specified. For example, the boundary of an event is not defined. In detail, what is the beginning and ending of an ‘EventObject’? How to define the semantic boundary between several events happening in succession? Such as, an earthquake results in a big fire. What’s condition should be defined as the beginning of this fire? Thus, the semantic information in this model should be specified more. This can be done at several stages.

Firstly, during the ontology capture step, it is needed to consider all semantic information as complete as possible. Secondly, during the step of ontology modeling, it is plausible to build the emergency management ontology into the hybrid architecture. In detail, we could build an ontology to define the meanings of the data in dynamic data model. Usually, dynamic data ontology needs some domain ontologies to refer to in order to get the exact definitions of the data in certain application domains. For example, when ‘MeasurementTask’ defines the task for measuring poisonous gas plume, a meteorology ontology is needed. When ‘MeasurementTask’ defines the task for measuring the flood, a hydrology ontology is needed.

However, sometimes, semantic information is related with specific context. Such as, in the generic dynamic data model, ‘DM-Users’ are involved in ‘Process’. But in detail, Fire Brigade department only involves in process No.1~7. However, Police department only involves in process No.11~17. Thus, these process-dependent information should be linked together. Usually, rules are introduced to link them, which has the form of ‘IF...THEN...’. For example, ‘IF a fire happens THEN Fire Brigade should take part in processes No.1~7’. The rule is a logic condition which guide the ontology reasoning resulting in target information.

Then, is a time ontology needed as well? As time is very critical

for emergency management, information getting from affected field may have time validity. For example, the affected area by the incident may change by time. The GRIP level and scale of the incident also may change by time. Currently, the time is modeled as property/attribute of the corresponding object. However, it might be worthy investigating whether a time ontology could be built to define the clear boundary of time states: before, after, during, etc. On time A, the affected area is computed. The GRIP level is defined. Then, corresponding processes of the GRIP level are activated, as well as the actors. On time B, the affected area may enlarge, which may result in higher GRIP level and further more actors. Such information could be linked together by the same time class in time ontology to keep the time consistency of the disaster. Moreover, the durations of integrating C&C information, updating them and then distributing them to target actors could be assigned max time limits by referring to the time ontology. Then, it might be easier and faster to control the dynamic data flow between different classes.

The dynamic data ontology and the static data ontology have to be linked since the actors in emergency management need both. During the processes of ontology linking, it could be possible to combine the semantic mapping method with non-semantic mapping method together. For example, it is common to match the vocabulary of concepts first, and then to compute whether they have logic (spatial) relationships with each other. The main structure of the emergency management ontology is shown as follows.

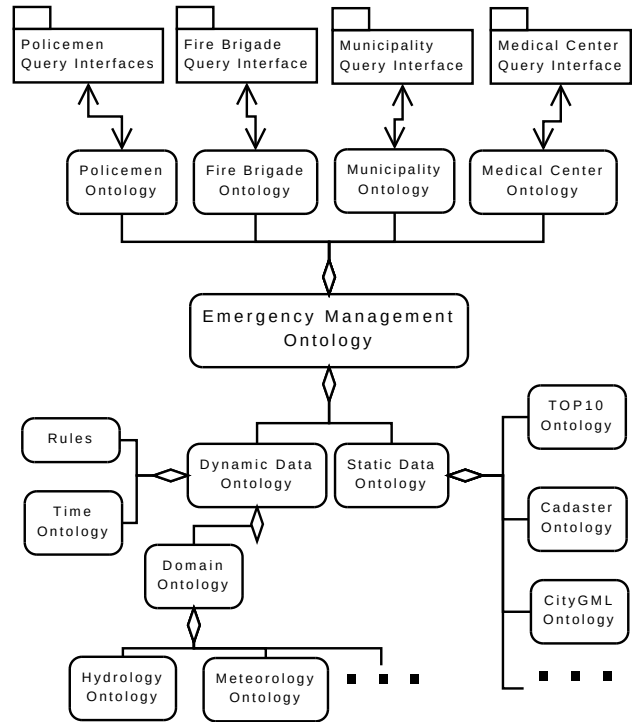


Figure 6: Emergency Management Ontology

The emergency management ontology has two main parts. One is dynamic data ontology, the other is static data ontology. Dynamic data ontology consists of domain ontologies needed for specific disaster, time ontology, etc. and rules. Static data ontology is composed of various kinds of data ontologies. Besides, actors have their ontology in emergency management ontology, which defines the vocabulary in their daily work. Corresponding to these four actors’ ontologies, there are several query interfaces connecting with emergency management ontology by link-

ing with actors' ontologies. These interfaces accept the queries from the actors and search the target data from emergency management ontology, then sending the results back to the actors.

In conclusion, ontology may help represent semantic information of emergency management in two points. Firstly, ontology provides uniform definitions on the data used in emergency management. Because on one hand, actors of emergency management is not technical experts, so they could not understand the words used by technical experts, who have been responsible for maintenance of the different models. On the other hand, different application domains, such as, hydrology, meteorology, etc. specify different meanings on the same concept, it is hard to integrate their information together. Ontology assigns a uniform explanation on the concept that agreed by both experts and actors, as well as different domains. Then, this kind of explanation could act as a bridge between experts and actors and between different application domains for understanding. Secondly, if the concepts and relationships are clearly defined, context-related information could be distributed to the actors correctly. For example, if the data in emergency management are labeled with explicit definition on their context, it is low possibility to deliver them to unrelated actors. Therefore, by using the emergency management ontology, actors of emergency management could query the information from their query interfaces to get the wanted data in order to save the people suffered from the disaster.

6 CONCLUSIONS AND FUTURE WORK

In the paper, we analyze the possibility of applying ontology to resolve the semantic interoperability of emergency management. To illustrate the problems and analyze applicably of using ontology in emergency management, a simple scenario is introduced. We believe ontology may helpful when integrating data models with user models, doing semantic-related operation on spatial data, as well as helping actors extract context-related information. We elaborate on an emergency management ontology using a dynamic data model and several familiar to us static data sets.

The presented work is still at very early stage. In the near future, we will build the emergency management ontology proposed in this paper in several stages. Firstly, we will represent several static data models in ontology, such as Cadaster and CityGML. Actually, these models have already been represented in UML. We are going to find out how to derive formal definitions in the UML model to convert to OWL model. Secondly, the dynamic data model will be represented on OWL. Tools will be investigated for automatic conversions from UML to OWL. Special attention will be paid on the formal definition of concepts, properties and relationships between them. In this ontology, several rules are specified to indicate the specific relationships between certain concepts, such as process and actor. After this step we will establish possible links between the ontologies of the static and dynamic data. We are going to edit the ontology in Protégé. The ontology reasoning will be realized by RACER. At last, several actor queries will be set to test whether target information can be computed correctly to the right actor with the help of the emergency management ontology.

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