Emergency Decision of Meteorological Disasters: a Geo-Ontology Based Perspective

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Abstract. In view of geographical characteristics of meteorological disaster system, in this paper, we proposed a geo-ontology based model which is supposed to formally conceptualize the domain terms and establish the relationships between those concepts. Resort to the object-oriented analysis and design method, the class hierarchy and relationships between them is implemented finally at top-level, domain-level/task-level, application-level. The multi-level ontological model provides a universal foundation for knowledge representation of emergency management of meteorological disasters, which possesses some characteristics of flexibility, extensibility, compatibility. In future work, we will elaborate and implement the proposed geo-ontology model. This work will underlie the semantic integration among human beings, between heterogeneous systems and between human beings and systems and enable advanced emergency decision.

Introduction

Meteorological disasters are among the most severe natural disasters for almost all nations in the world. The analysis of disaster statistics compiled for the period 1967-1991 indicates a rising trend in the number of people affected by natural disasters. The statistics also indicate that extreme meteorological and hydrological events account for 62% of all events recorded as natural disasters. If those associated with weather events are included, the percentage rises to 85%. Over the same period, about 3.5 million people were killed by meteorological and hydrological events, while about 2.8 billion were affected by them (Obasi, 1994). United Nations reported, in total, 739,930 people died from meteorological disasters directly during 1947-1980 (Yang and Zhao, 2007). Global climate change is supposed to cause increasingly frequent weather anomalies all over the world, which further aggravate the risk of meteorological disasters.

In order to strengthen the emergency management of meteorological disasters and increase the capability of preparedness, mitigation, response and recovery for meteorological disasters, Risk assessment and emergency response decision have been paid much attention by worldwide researchers and emergency staff. The former provides goal and reference for emergency resource planning, allocation, specialist training, and compilation of emergency plans while the latter provides support for scientific and effective act on the disaster. In currently existing studies of risk assessment and emergency response decision of meteorological disasters, domain knowledge is seldom systematically modeled and considered. On the other hand, more and more researchers recognize the importance of incorporating semantic information in modeling and analysis for support of emergency management activities such as safety planning, risk assessment, emergency response decision across multiple agents. The heterogeneity of the information is a problem that limits most of these activities that use them. The semantic or logic relationships among those components comprising meteorological disasters play no less role in emergency analysis and decision-making. These semantic relationship includes topology, hierarchy, scale, order, constraint etc. How to model, represent and retrieve these kinds of semantic relationship is currently being paid much attention from academic researchers.
This paper is organized as follows. Section 2 introduces the meteorological disaster system, which provides substantial concepts and relationship for the ontology based representation of the domain knowledge in section 3. In section 4, the application of the proposed ontology is illustrated with an explanation of prediction of secondary & derived disasters of an original meteorological disaster. In section 5, we arrive in our conclusion and make a prospect of the further work.

**Meteorological Disaster System**

Many researchers argue that disaster system is composed of hazard factors, hazard-bearing body and hazard-inducing environment, or the likes (Wang et al, 2012). Disaster weather or climate event is thought of as the hazard factors of meteorological disaster. It is different from meteorological activities such as rainfall, temperature increase/decrease, air motion. Only when these kinds of meteorological activities are significant different from a normal level, they will trigger disastrous weather or climate event. Hazard-bearing body include human, things and system (which is coherently formed from human or things manually or naturally). Hazard-inducing environment is referred to as some macroscopic natural or social determinants of meteorological disasters. Some other researchers also propose an additional component generally called emergency management which represents human intervention to the above components (Fan et al, 2009). Meteorological disaster system, as a subset of disaster system, can be delineated through these theoretical frameworks. In this paper, we adopt the framework of meteorological disaster system proposed by Zhang et al (Zhang et al, 2016).

**Geo-Ontology Based Representation of Meteorological Disaster System**

**Different Kinds of Ontologies**

Some researchers defined ontology as “An ontology is a formal specification of a shared conceptualization” (Gruber 1992, Borst 1997). Ontologies are one of the popular forms used in semantic representation, and they have less limitation in modeling domain knowledge than other forms. Ontologies are designed to provide a consistent recognition of domain knowledge, and share and communicate them among human beings, between heterogeneous systems and between human beings and systems.

Guarino (1998) defines several levels of generality that give rise to different types of ontologies: Top-level ontology, domain ontology and task ontology, application ontology.

Formally conceptualizing the domain terms and establishing the class hierarchy is the first step to build up an ontology. This is generally accomplished with object-oriented (OO) analysis and modeling techniques, by which the concepts are mapped to classes and the relationships between concepts are implemented with several popular relationship representations between classes such as inheritance, realization, dependency, association, composition, aggregation and so on. To create a semantic network connecting different classes and describing their characteristics, properties need to be carefully defined. Object Property defines the relations between two objects and it works as a bridge linking two individuals from different parts of the class hierarchy. Data Property acts more like the innate attribute of an object and it describes relations between individuals and data values.

**Geo-Ontology Based Meteorological Disaster Knowledge Representation**

Zhang et al. (2015) have preliminarily explored construction and application of meteorological disaster system, and proposed a model called meteorological disaster ontology.

In those researches, geo-spatial factors are considered seldom. However, meteorological disaster system is a typical kind of structure and process inherently bound to space and time. Disastrous weather/climate events happen in a certain location (or area) and time (or a period of time), hazard-bearing bodies are some spatial existence and usually have to be referenced in a space-time context, and hazard-inducing environments are also a geographic (or geographically referenced)
background. As a result, it is essential to consider geographic location specific semantic relationships between concepts of the meteorological disaster domain.

Xu et al. (2014) proposed the three-layer modeling primitives to provide the foundation of the earthquake disaster emergency response (EDER) knowledge representation which are considered a top-level ontology. In the modeling primitives, abstract geographical modeling primitives and geographic modeling primitives together compose the geo-ontology.

Taking geographic modeling primitives as parent classes, we derive the domain ontology, task ontology and application ontology of meteorological disasters.

**Domain Ontology.** Domain ontology describes concepts existing in meteorological disaster system and the relationships between these concepts. According to the section 2, the meteorological disaster system is composed of three components: disaster meteorological events (DME), Hazard-bearing bodies (HBB) and hazard-inducing environment (HIE). Inherently these components are linked with a geospatial context and geographical characteristics should be considered properly, which can be implemented through inheriting the corresponding classes (concepts) from the geographic primitives (Figure 1).

![Figure 1. The levels of meteorological disaster ontology derived from the geographic primitives.](image)

Some researchers classify the meteorological disasters occurring in China into seven types and thirteen subtypes. According to this, we can build up the hierarchy of disastrous meteorological events (Figure 2).

![Figure 2. Domain ontology hierarchy of the concepts of meteorological disaster system.](image)

**Task Ontology.** Task ontology is constructed to provide semantic support for some activities of emergency management of meteorological disasters. Task ontology aims to represent disaster general
knowledge. i.e. these knowledge is commonly usable for various meteorological disasters. So some general procedures and rules should be represented in this level of ontology.

**Application Ontology.** Application ontology is to model disaster specific knowledge. These knowledge includes factual knowledge, rule knowledge and procedural knowledge and has different levels of granularities. Nonetheless, the knowledge is different from one disaster to another disaster. Generally, application ontology is derived from specifying task ontology according to specific procedures, behaviors, rules, goals etc. for example, when faced with the prediction of potential secondary & derived disasters for a typhoon, we need launch a typhoon path analysis model to analyze the affected scope by the typhoon and take a static structure of typhoon disaster chain as input of the reasoning procedure. These applications ask for typhoon specific knowledge such as typhoon path analysis model, typhoon disaster chain and so on and the task ontology cannot service these kinds of knowledge for them.

**Ontology Based Reasoning**

Once the meteorological disaster ontology is well constructed, it can provide decision semantic information for emergency decision of meteorological disasters including routine and urgent activities such as resource planning, prediction of secondary disasters, countermeasure compilation. In the course of these activities, some judgment and decision analysis need to be made based on some rules which can be retrieved from the meteorological disaster ontology (this is also the most important advantages why we construct an ontology model).

Meteorological disaster ontology itself provides domain knowledge representation of meteorological disasters, which formalize the associated knowledge at different levels. As a result, they can cater to the needs for analysis and reasoning in different decision goals of various tasks of emergency management. Thanks to the complement of geographical items in the ontology model, the complex process occurring in meteorological disaster system can be described more fully. Thus, emergency decision is supposed to attract more interest.

**Conclusions and Future Work**

Emergency decision plays important role in augmenting resilience before a meteorological disaster happens and reducing loss of life and property when a meteorological disaster happens. Development of artificial intelligence bring opportunity to provide a computer-aided problem-solving approach, which enables making of scientific countermeasures and rapid response for some activities (including routine and urgent) involved in emergency management of meteorological disasters. With aid of formalized domain knowledge, computer can retrieve and utilize them automatically. In addition, when faced with each of these activities, some heterogeneous systems and multiple agents have to share and exchange information among each another. Semantic integration is essential in order that they collaborate smoothly.

We preliminarily explore the application of ontology in modeling meteorological disaster system. In view of inherent geographic characteristics of meteorological disaster system, a geo-ontology based approach is proposed in this paper. We analyze the concepts and relationships between the components of meteorological disaster system and tentatively give the preliminary framework of the geo-ontology of meteorological disaster system. As a result, the potential application of the proposed geo-ontology is illustrated with an explanation of prediction of secondary & derived disasters of an original meteorological disaster.

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