Ontology-based Modeling of Emergency Incidents and Crisis Management

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ABSTRACT

With the frequent occurrence of emergency incidents in recent years, developing intelligent and effective decision support systems for emergency response and management is getting crucial to the government and public administration. Prior research has made many efforts in constructing crisis databases over the decades. However, existing emergency management systems built on top of these databases provide limited decision support capabilities and are short of information processing and reasoning. Furthermore, ontology based on logic description and rules has more semantics description capability compared to traditional relational database. Aiming to extend existing studies and considering ontology's reusability, this paper presents an approach to build ontology-based DSSs for crisis response and management.

Keywords

Emergency Decision-making, Emergency Incidents, Ontology

INTRODUCTION

Emergency incidents (EI) refer to events that occur in a sudden, causing or being able to cause social damages, and need to be dealt with by means of urgent measures. These EIs usually cause huge financial and life loss, or even loss of lives. In most EIs, the public emergency medical services resources, such as personnel and equipment, are overwhelmed by the number and severity of casualties. The general public commonly recognizes events such as building collapses, train and bus collisions, earthquakes and other large-scale emergencies as emergency incidents. Events such as the Oklahoma City bombing in 1995 and the September 11 attacks in 2001 are well publicized examples of emergency incidents.

Timely response to emergency incidents is crucial to prevent current situations getting worse and thus reduce the number of casualties and other potential damages. Although quite some efforts have been put into both research and practice in crisis management, the reality is not satisfying. On the other hand, previous studies show that, ontology based on description logic and rules can further describe the semantics of relational databases [1]; logic-based knowledge representation can effectively improve the ability to express the semantics of the knowledge and the corresponding logical reasoning algorithm can improve the ability of knowledge discovery and interpretation [2]. Therefore, by analyzing some research progress on emergency decision-making, we explore the modeling of emergency management based on description logic and rules. Furthermore, a systematic approach to construct OWL ontologies from relational databases is presented, which describe processing steps of extracting semantic information from relation schema, including entity, relation, inheritance, aggregation and cardinality ratio constraint. We accomplish the transformation of relational database semantic information to corresponding elements of ontology. At last, we verify the consistency and effectiveness through the prototype system to support logical reasoning and disaster management.

BACKGROUND

Emergency Incidents and Crisis Management

According to the Emergency Handling Law enacted in 2007 in People's Republic of China, there are four categories of EIs: natural disasters, accident disasters, public health incidents, and social security incidents. Every category can be subdivided into several sub-categories. For example, natural disasters can be divided into flood, rainstorm, debris flow, and tsunami etc. Historical data of emergencies exists in various forms, such as news reports, investigation reports, summary reports and so on in the real world. From the perspective of decision support, the circumstance of emergency decision-making is subject to dynamic changes and the information needed to decide is usually incomplete and inaccurate, compared to decision-making in regular situations. What's more, decision-making in crisis management requires high effectiveness but carries large risk. Therefore, we need specialized theories and approaches to support emergency decision-making. Ody [3], Kathy [4] and other scholars studied patterns and processes of crisis response and management of sudden crisis. In the field of information management of emergency crises, researches on building crisis management databases and case bases have been conducted and some progresses have been made in trying to improve the usability of historical data of emergencies with query mechanisms derived from database management system. Disasters collected in these databases and case bases are of different kinds and the same disaster may have been described differently. In some circumstances, the data they collected are from different areas and only represent the information of an emergency from a single aspect. For example, Chinese Academy of Meteorological Sciences built databases for flood and rainstorm disasters, based on disaster information reported since the founding of the country, which summarize data of the occurrence time, disaster areas, rainfall, death toll, number of injury, collapsed building, direct financial loss, and so on [5]. Ministry of Civil Affairs, Ministry of Education, Academy of Disaster Reduction and Emergency Management, and Beijing Normal University studied and established China's natural disaster atlas which involves earthquakes, floods, typhoons, snowstorms, hails and other natural disasters, and includes nearly 400 maps and more than 50 statistical tables describing distribution of China's natural disaster and providing important information of China's main natural disasters graphically [6]. The disaster database built by University of Richmard in USA provides detail information about disasters. What makes it special is the different stages' developments of part of the disasters it records, but the shortage is that it records few natural disasters especially floods [7]. These basic disaster databases lay the foundation of this study. However, the relational database modeling structure is often relatively simple and its semantic expression ability is very weak. The contents with the same meaning cannot be retrieved if they were expressed in a different way. What's more, emergency crises are often of various kinds, with different characteristics, and involve tremendous causality. With historical data stored in traditional databases, it is difficult to find the logical internal relationship between any two crises. We believe that the historical data for emergency crisis management should meet their specific requirements. For example, policy makers do not expect a single data management and data query, but more of the understanding of the semantics, which supports semantic search and knowledge discovery, based on data available. Maio [8] described and analyzed the 'distributed' and 'networked' nature of emergency operations and put forward the notion information systems to support it, and that ontologies in this domain should be built accordingly. By semantically combining traditional databases with knowledge bases, we aim to provide more intelligent decision support for emergency crisis response.

Ontology and OWL

Ontology originated as a philosophical concept and then is used to explain and illustrate the concept extracted from the real world. Nowadays the most cited definition is what Studer [9] presented in 1995: An ontology is a formal specification of a shared conceptualization containing four features including conceptual, explicit, formal and sharing. Perez et al. [10] summarized that an ontology induces five basic modeling primitives through the analysis of existing ontologies, which includes classes (concepts), relationships, functions, axioms and instances, thus we can use a five-dimension feature vector O (C，R，F，A，I) to express an ontology. Based on the field dependency of ontology, it can be classified into top ontology, domain ontology, task ontology, and application ontology. When we establish the ontology model, we need to use an ontology language to represent the model. OWL [11] is one of the most popular ontology languages and the ontology language recommended by the WWW consortium. OWL provides more primitives to support richer semantic representation, compared to XML, RDF and RDFS, in particular, it adds more restrictions in terms of semantics in the property description and constraints. OWL comprises of three kinds of sub-languages including OWL Lite, OWL DL and OWL FULL which have increasing expressive abilities. OWL DL not only provides rich semantics but also has strong automatic reasoning ability, which suits our domain for representing and reasoning with crisis chains, so we choose OWL DL as the ontology modeling language in this paper.

META-ONTOLOGY FOR CRISIS RESPONSE AND MANAGEMENT

Now we analyze what a meta-ontology for crisis response and management should include in its definition. The description information of each crisis contains four parts: case type description, case problem description, solutions, and decision results. More detailed features include time, brief description, type description, region, geographical condition, weather condition, rainfall, wind level, traffic condition, flood frequency, disaster reason, disasters level, death toll, etc. A crisis response and management process comprise of several stages: problem definition, goal setting, solution design, solution selection, and implementation. Figure 1 explains a flow chart of the crisis response and management process.

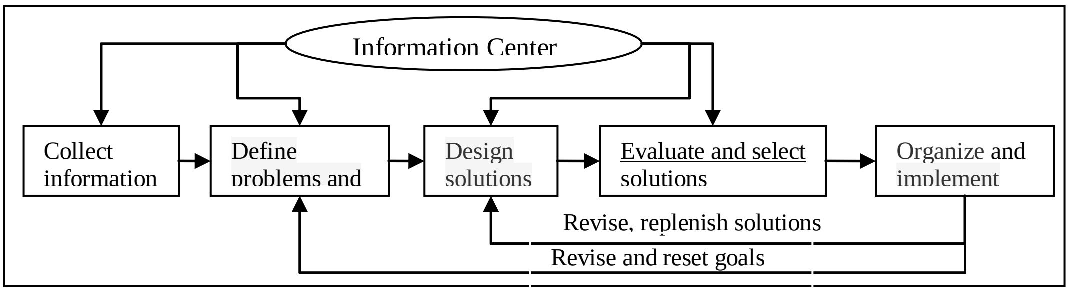

Figure 1. The flow chart of emergency decision-making

The stages in the above flow chart do not have to follow the exact order. The core issue here for modeling is to develop knowledge representation of the crisis response process of emergencies. When we describe a typical emergency case, we need at least a dual feature vector: <problem description, solution description>. To include decision results, a method using a three-dimensional feature vector can be adopted, <problem description, solution description, Result description>. But for the complexity and timeliness in crisis response and management, we usually have to extend the representation to a four-dimensional feature vector Case=<P,E,S,O>, where P is the description of the problem; E describes the decision-making environment, including internal and external environments of the system; S is the solution description, which is related to emergency measures; O is the state description when adopting S to the problem P or the feedback evaluation information. Based on these analyses, we proposed a typical logical structure of crisis response and management, as shown in Figure 2.

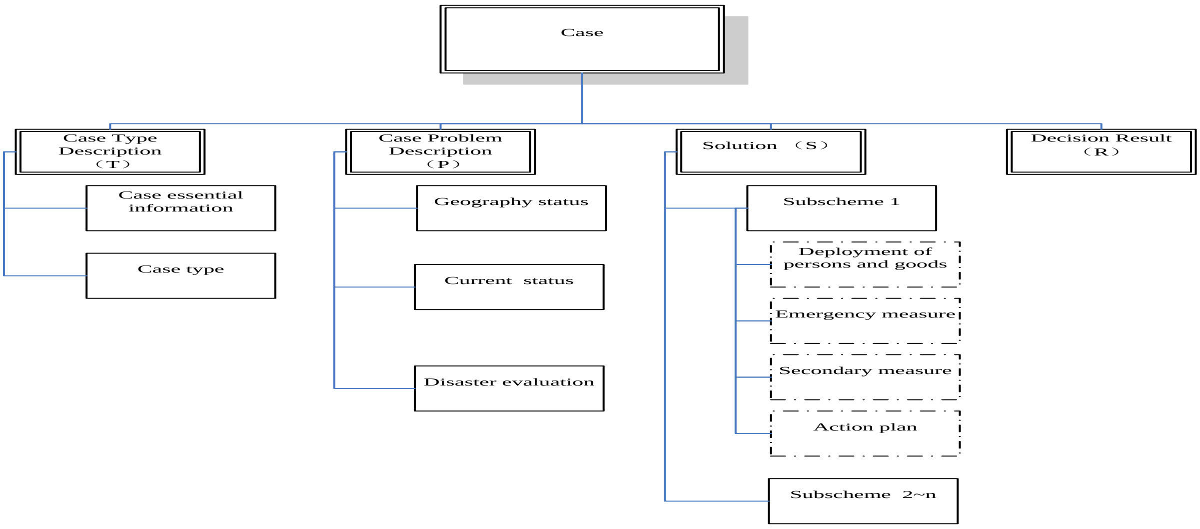

Figure 2. The logical structure of emergency decision-making

The development of an emergency has obvious logical causal relationship. For example, prolonged heavy rains cause flood and longtime flood leads to urban water logging. What the above-mentioned logical structure constructs is a static case, every status records a time point and the decision-making is also based on this particular time point. The development of emergency is a dynamic process under ordinary circumstances, while the static case cannot describe the complete process accurately. Therefore, we propose a dynamic way to organize the knowledge representation of the case. After we determine the organizational form of dynamic case and the different stages in the form which we use the term status, we can get beyond the logical representation of a dynamic case.

A dynamic case is composed of n status (n static case, corresponding to different crisis response stages), each status connects to a prior status and a next status, the status change leads to the next status to generate. New information and new decision resolution results in the new status when the status changes. The number of status for a dynamic case is unlimited, depending on the dynamic changes of an emergency. A dynamic case can then be stored in the form of a static organization structure and the dynamic structure of the case is to achieve through a case pointer. Each case has a static field Case ID, which is to uniquely identify each static case. The basic message of a static case contains a prior status pointer and a next status pointer, which is used to point to the previous and the next status of the current case [12].

APPROACH TO BUILDING AN APPLICATION ONTOLOGY

A framework of construct an application ontology

Based on the meta-ontology, we then construct domain ontologies from dynamic cases which are organized and stored in an ER model based database in the static form. The issue here is how to transfer the ER model of a crisis database to an application ontology model. Review that a relational database contains several tables, each of which contains multiple fields and the value of field data are table records; while ontology contains classes, each class contains many properties, and an attribute value is taken as an instance. Table and class, field and property, records and instance seem to exist some corresponding relations; therefore, it is possible to establish some kind of mapping from a relation database to application ontology. Figure 3 shows the four stages of constructing application ontology for crisis management and response.

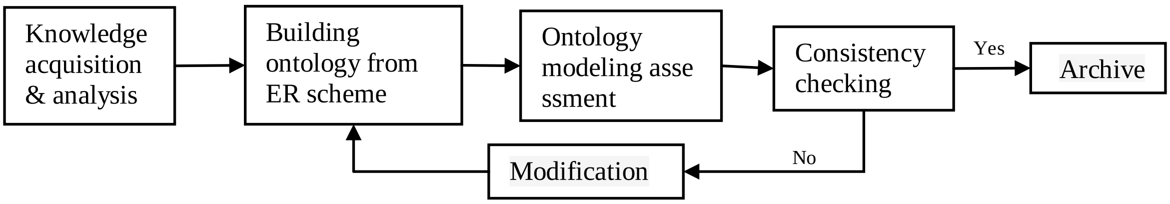

Fig 3: Construction stages of domain ontology

We first analyze the characteristics of the emergency decision-making field to obtain the specific knowledge and establish the pattern of relationships. The most important thing is to include table names, fields, field types, primary keys, foreign keys, dependence between relationships, and other information. This information obviously comprises important components of resulting domain ontology. Then according to some established mapping rules addressed in the next section, we convert the collected knowledge into basic ontology elements and ultimately build an application ontology model. At last, we assess and analyze the converted model to check whether all the tables, relationships between tables, attributes and constraints of attributes are converted into the corresponding elements of the ontology model. And finally the intermediate progress was analyzed to find whether the domain ontology model is logically consistent. If the domain ontology model passes the inspection then it will be archived. Otherwise we will turn to the second step and make some modification.

Mapping rules

Base on general mapping rules from the ER model of a relational database to ontology [13], we propose the specific rules which map to a crisis management domain application ontology: (1) Rule 1: Convert database tables into homonymic ontology classes. If some tables' primary keys are the same, we can merge them into a single class. (2) Rule 2: If the relational database has inheritance relationships between two tables, the name of a table will be declared as a homonymic subclass and the other table is declared as a homonymic parent class. (3) Rule 3: If the relational database tables contain non-foreign key fields, we convert them into homonymic datatype properties. Each property's domain is the class name and the range is the type of data. (4) Rule 4: If the relational database tables have foreign key fields, we convert them into homonymic object properties, the domain of each property is the corresponding ontology class name, and the range is the ontology class name of a table in which the corresponding field is a primary key. (5) Rule 5: If the value of a non-foreign key value does not allow being empty, the constraint value of its corresponding datatype property limits as 1; if it allows to be empty, the constraint value of the corresponding datatype property limits maximum as 1. (6) Rule 6: If a foreign key value does not allow being empty, the constraint value of its corresponding object property limits minimum as 1; if it allows to be empty, the constraint value of its corresponding object property limits minimum as 0.

SYSTEM DESIGN AND APPLICATION EXAMPLE

The ontology construction prototype system includes the following components: (1) Obtain the relational database schema and data records; (2) Analyze the relation schema of the database and identify tables, fields, and constraint information; (3) Transform the relation scheme into the ontology elements with the rules engine; (4) Transform the database records into ontology instance using mapping rule seven; (5) Verify and store the generated OWL DL ontology document. We choose JAVA as the programming language as there exists several ontology APIs in Java such as Jena and OWLAPI and it is easy for ontology integration and data mining process in our future work. We use Drools, an open source business rules engine based on Charles Forgy's RETE algorithm implemented as an Eclipse plug-in, to define and realize the mapping rules. Figure 4 presents the final results given by the prototype system using the existing database we constructed in previous work using Mysql.

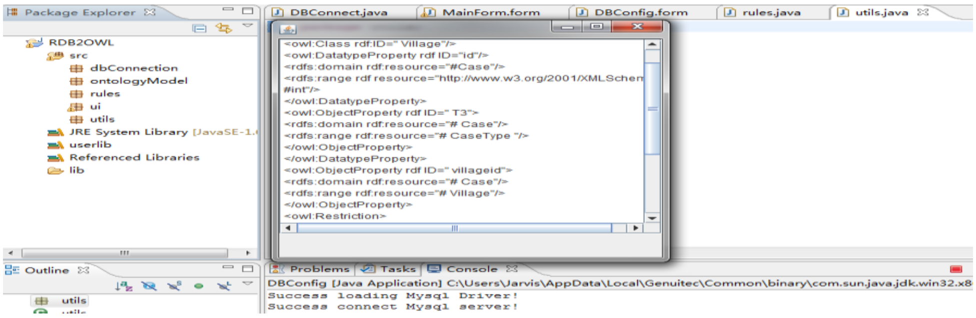

Fig 4： Testing result chart of prototype system

CONCLUSION

This paper mainly studies the knowledge feature and ontology construction based on the crisis response and management. We first present a methodology for modeling crisis and crisis management knowledge, and then propose the corresponding mapping rules between relational database and domain ontology, design and realize the ontology construction prototype system, and finally we illustrate the approach with an application example.

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