Fine-Grained Ontology Reconstruction for Crisis Knowledge Based on Integrated Analysis of Temporal-Spatial Factors†

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Abstract: Previous studies on crisis knowledge organization mostly focused on the categorization of crisis knowledge without regarding its dynamic trend and temporal-spatial features. In order to emphasize the dynamic factors of crisis collaboration, a fine-grained crisis knowledge model is proposed by integrating temporal-spatial analysis based on ontology, which is one of the commonly used methods for knowledge organization. The reconstruction of ontology-based crisis knowledge will be implemented through three steps: analyzing temporal-spatial features of crisis knowledge, reconstructing crisis knowledge ontology, and verifying the temporal-spatial ontology. In the process of ontology reconstruction, the main classes and properties of the domain will be identified by investigating the crisis information resources. Meanwhile the fine-grained crisis ontology will be achieved at the level of characteristic representation of crisis knowledge including temporal relationship, spatial relationship, and semantic relationship. Finally, we conducted case addition and system implementation to verify our crisis knowledge model. This ontology-based knowledge organization method theoretically optimizes the static organizational structure of crisis knowledge, improving the flexibility of knowledge organization and efficiency of emergency response. In practice, the proposed fine-grained ontology is supposed to be more in line with the real situation of emergency collaboration and management. Moreover, it will also provide the knowledge base for decision-making during rescue process.

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1.0 Introduction

Crisis information refers to a large number of disordered information produced by emergencies in a short period of time, including not only the information generated during the crisis but also the emergency plan, an investigation report, evaluation results, and other information created in crisis management (Braun, 2015). The rapid and effective collection, analysis, and transmission of crisis information can reduce the loss caused by crisis events (Ley et al., 2014). Crisis knowledge management could help the crisis managers to clearly perceive the crisis situation and to quickly make decisions (Muhammad et al., 2015). Among these studies, crisis knowledge organization is one of the crucial parts of crisis knowledge management. The construction of a knowledge base for emergency response and the organization of knowledge related to emergencies will not only improve the efficiency of emergency response but also provide reference for similar crisis cases (Ludwig et al., 2015). In the field of knowledge organization, ontology has become one of the common methods because of its contribution to the sustainable knowledge management and intelligent decision support. However, the construction of a crisis knowledge ontology is mostly based on the classification of static knowledge concepts from the coarse-grained semantic level, ignoring the dynamic effect at the feature-level. Most of the studies did not consider the temporal and spatial features of crisis knowledge and its dynamic organization in a big data environment, especially the interaction under temporal-spatial characteristics. For these reasons, we aim to put forward a fine-grained reorganization of crisis knowledge from the perspectives of temporal-spatial factors in this study, which is a new framework for the conceptual classification and characterization of crisis knowledge by considering its dynamic features. More specifically, the research questions needing to be addressed to are as follows:

> RQ1: What is the approach to identify the static and dynamic status of crisis knowledge and then to describe its temporal-spatial features?
>
> RQ2: How can fine-grained crisis ontology be constructed by emphasizing the integrated analysis of temporal-spatial features for crisis knowledge?

In order to find answers to these research questions, a cross-composite analysis method will be illustrated. Based on this, a crisis knowledge ontology will be reconstructed from the characteristic units to represent the dynamic changes from three dimensions: temporal relationship, spatial relationship, and semantic relationship. It should be emphasized that this ontology model is a fine-grained knowledge representation method based on the analysis and characterization of crisis knowledge features. Furthermore, a crisis case addition and real-time interactive interface will be given to complete the ontology verification. This knowledge organization approach will further enrich the crisis knowledge types and attribute values under the temporal-spatial characteristics. Meanwhile, it may provide a new idea for the dynamic and collaborative decision-making in the crisis management and system design.

The paper is organized as follows. In Section 2, related studies on the ontology-based crisis knowledge organization will be reviewed. Then the temporal-spatial features analysis and crisis ontology reconstruction will be introduced in details in Section 3. The ontology verification and crisis knowledge query will be provided in Section 4. In Section 5, the research findings will be discussed. And finally, there will be suggestions for further study.

2.0 Related work

In this section, related work mainly involves two aspects: crisis ontology construction and time and space analysis in information management (seen in Table 1). For these two parts, detailed review and summary will be made in Sections 2.1 and 2.2 respectively.

Research contents	Classification	Application / Examples
Ontology-based crisis knowledge organization	Ontology-based crisis knowledge properties	Different forms of knowledge (Hu et al., 2012) (Santos et al., 2011)
		Derived properties of knowledge (Wang et al., 2011) (Huang et al., 2011)
	Ontology-based crisis situations	Different periods and scenarios of crisis (Damrongrat et al., 2014) (Soden and Palen, 2016)
	Ontology-based services under crisis knowledge	Ontology-based knowledge sharing (Manica et al., 2010) (Spalazzi et al., 2014)
		Ontology-based decision making (Husáková, 2016) (Simas et al., 2017)
Information analysis considering the factors of time and space	Wide range of applications	Information analysis in transport, agriculture, network data management, etc. (Laksmiwati et al., 2014) (Wang et al., 2006) (Jensen and Snodgrass, 1999)
	Various technologies used	Information analysis by applying GIS, XML, etc. (Dambreville and Le Cadre, 2004) (Soile et al., 2015) (Apostolopoulos and Daskalou, 1997)

Table 1. Summary of existing research on the crisis ontology and temporal-spatial information analysis.

2.1 Ontology-based crisis knowledge organization

The studies concerning ontology-based crisis knowledge organization could be illustrated into three aspects, including nature of crisis knowledge, crisis situation, and crisis knowledge services.

The ontology construction based on the nature of crisis knowledge often focused on two aspects: expression and attributes of knowledge. Common expressions of crisis knowledge involved paper documents and electronic data like photo, video, audio, etc. Based on the different features and attributes, crisis knowledge could be grouped into objective knowledge and derivative knowledge (Onorati et al. 2014). Objective knowledge contained objective features such as time, place, and the evolution mode of crisis, while the derivative knowledge included the knowledge that accompanied the crisis such as command decision, medical rescue, and news communication. Meanwhile the derivative crisis knowledge could also be classified as events, operations, personnel and organization, resources, time, and place (Bitencourt et al. 2015).

The ontology-based crisis knowledge organization based on the crisis situation was constructed in accordance with the process of crisis evolution. In emergency management, life cycle theory was usually formed through these four-step stages: mitigation stage, disaster preparedness stage, coping stage, and recovery stage (Sergey et al. 2013). Similarly, the crisis development cycle also contained occurrence mechanism, development mechanism, and evolution mechanism, which was classified from the knowledge changed trends of emergency field and the evolution process of the event (Sergey et al. 2012). The ontology construction based on the crisis knowledge services emphasized two perspectives: descriptive services of crisis knowledge and knowledge-based decision making. Based on various knowledge functions, Zhong put forward that top ontology and domain ontology usually included basic conceptual relationships and related backgrounds, which provided the description functions. Meanwhile, task ontology and application ontology modeled the knowledge for a particular crisis event under decision functions (Zhong et al. 2017). According to these different services provided by crisis knowledge, semantic technology was used to design an ontology of management of crisis vocabulary (MOCV), which could analyze a large number of social media data and propose an emergency monitoring system (Abinaya et al. 2015).

In addition, there were some crisis ontology constructions that take into account the factors of time and space location (Dutta et al. 2014; Buchel and Sedig 2011). For example, some researchers (Wiegand and García 2010; Kaipainen and Hautamaeki 2011) proposed creating a geospatial semantic web, which provides users with real-time search data. From the perspective of graphic mode, Laksmiwati et al. (2013) used a specific time frame to provide disaster information, not just text mode. Considering different scenario theories, the researchers (Moreira et al. 2015) discussed the challenges related to the concept of scenario modeling in the disaster management ontology. Besides, many researchers have used different methods such as discrete mereotopology (DM) (Kurte et al. 2019), DL-safe rules (Kurte and Durbha 2016), 4D-fluents approach (Kurte et al. 2017), parametric approach (Sinha and Dutta 2020), etc., to construct a dynamic flood ontology and discuss the changes of time and space factors.

From the previous studies, it was found that ontology-based crisis knowledge organization systems paid more attention to the classification of concepts or visualization of temporal and spatial crisis knowledge but ignored the dynamic structural changes of crisis knowledge under the composite influence of temporal-spatial.

2.2 Information analysis considering the factors of time and space

With the advent of big data, information no longer took into account the factors of time and space. It was found (Wolbers et al. 2013; Abbasi and Kapucu 2012) that the information analysis considering the dynamic characteristic was usually expressed by time series and the visualization of geographical position.

Information analysis reflected in the time factor could be understood as the timeliness of information, such as the acquisition, processing, and utilization of real-time information (Dumais, 2010). A series of information on time distribution points and their tendency played an important role in many management fields (Park and Koh, 2015). For example, for traffic information management, a traffic safety service platform based on the synergy of vehicle and road facilities was proposed (Wu et al. 2016). Besides, a model of a urban public transport information collection system for the internet of things was also considered (Kim et al. 2016) in the real-time transmission of information. In the field of medical management, intelligent anesthesia management was used (Rasheed et al. 2016) to detect the hypertension and hypotension in real time. These studies related to the time factor emphasized the overall process of information management, so that the management decision and the production control could be carried out according to the real-time information.

Information analysis with a spatial factor reflected the distribution of information at a certain spatial range. For example, in the field of environment, the government obtained the distribution of natural disasters through information sharing and formed emergency management measures (Yadav et al. 2014). In the area of energy, a comprehensive control of a sustainable ecosystem and energy distribution could be carried out in conjunction with a geo-visual analysis (Pisica et al. 2013). From the technical approach, information analysis with the spatial factor including web GIS technology, IoT technology, GIS visualization technology, etc., (Kjersti. 2014; Brown et al. 2014) could be seen as information analysis related to the spatial factor mostly contained the information elements with geographical attributes to realize the global representation of information content (Pohl et al. 2018).

In the field of crisis management, the time factor was mainly reflected in the requirements of time urgency. On the one hand, the completion of rescue in the shortest time was the fundamental goal of emergency management (Wu et al. 2013). On the other hand, the management of crisis at each time node has become an important reference for the continued implementation, correction, or termination of the next stage of cooperation. The space factor was also the main element in the collaborative emergency management (Reuter et al. 2014). First, it determined the overall cognition of the collaborators to the crisis situation, which was the basis of the communication among collaborators. Second, the establishment of the space dimension could help in rescue personnel, schedule, materials, and estimate of environmental impact (Moehrle 2012).

From the previous research, it could be revealed that the time factor and the space factor had important influence on the information management for a plurality of fields. The dynamic interaction of information could be improved and the changes of information in a certain time period at a certain range would also be reflected. However, the application of time and space factors to dynamic knowledge organization and ontology construction has been ignored, which could illustrate the dynamic attributes and changing trends of crisis knowledge.

2.3 Motivation

Concluded from the previous studies, although temporal-spatial factors were noted in crisis management, they were not simultaneously applied to the dynamic organization of knowledge nor to the ontology construction at the feature-level. Therefore, this article will propose a fine-grained crisis knowledge ontology by integrating temporal-spatial analysis to solve above problems of dynamic organization of crisis knowledge.

The specific innovations of this study are as follows. First, temporal and spatial factors are segmented according to sequences and scenes, based on which the cross-effects of their dynamic changes will be analyzed. More specifically, in the process of time analysis, the development of the crisis is divided into varied stages according to the life cycle theory. Then the time concepts will be used to describe the crisis knowledge of each stage. In the process of spatial analysis, the regional disaster levels and spatial coordinate were used to describe the spatial attributes of crisis knowledge. During the analysis, the crisis knowledge organizations are dynamically changing under the joint effect of time and space is emphasized. In other words, the division of time series and spatial regions have overlapped influences on the organization of crisis knowledge, and the two are not independent. Second, a fine-grained dynamic knowledge organization of feature units from the perspective of composite temporal-spatial relationships will be proposed, which is supposed to express the dynamic semantic knowledge structure more ac-

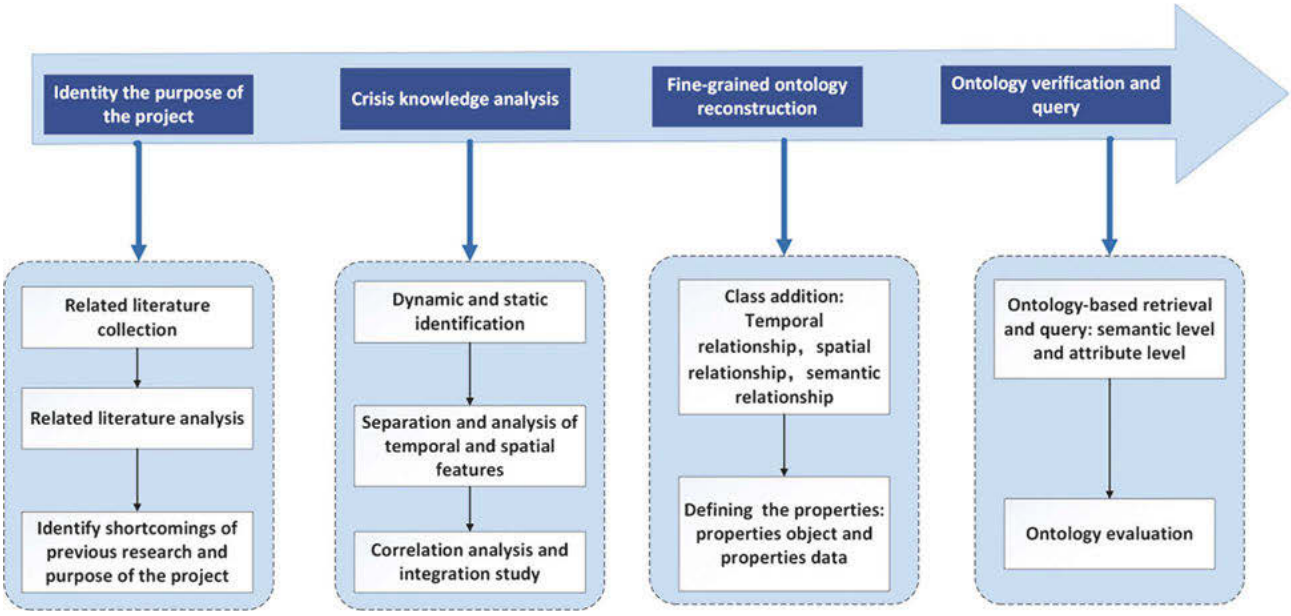


Figure 1. The procedure for reconstructing the crisis knowledge ontology.

curately. The fine-grained ontology is mainly reflected in the analysis and representation of the dynamic features of crisis knowledge. In this process, the changes of semantic relations are characterized from the perspective of temporal relations and spatial relations. The construction of the ontology model will put more emphasis on the change and expression of the relationship between the temporal-spatial features.

3.0 Reconstruction of fine-grained crisis knowledge ontology

Researchers have proposed different models for crisis information communication (Yang and Wu 2019), crisis information dissemination (Regester 1987), and technology application (Matta et al. 2012) in crisis information management. However, researches on ontology-based crisis knowledge dynamic representation model are ignored. Thus, in this study, we propose a fine-grained crisis ontology model based on temporal-spatial composite analysis to solve the two research problems mentioned in the introduction. The specific research methods are as follows:

> The composite analysis method of temporal-spatial characteristic will be put forward to solve the first research problem mentioned in the introduction. More specifically, this study will focus on the static and dynamic attributes of crisis knowledge under the interaction and composite effects of temporal-spatial factors. In order to deal with the second research question, a fine-grained crisis knowledge reconstruction of the characteristic units will be proposed to organize the crisis knowledge resources effectively, which displays the crisis concepts and their relations dynamically and completely. This dynamic ontology model of crisis knowledge is realized from three aspects: temporal relationship, spatial relationship, and semantic relationship. The temporal relationship and spatial relationship are used to describe the changing process and trend of crisis knowledge, and the semantic relationship is used to indicate the dynamic organization of crisis knowledge under the superposition of temporal-spatial.

The skeletal methodology is formulated in this study to implement the ontology reconstruction (Uschold and Gruninger 1996; Wu and Shi 2016) (seen in Figure 1). There are four main steps. At the first step, the fine-grained ontology construction scope will be clarified and related knowledge will be collected. Next, the temporal-spatial features analysis of the crisis knowledge will be proposed. Then the processing properties will be demonstrated, and the ontology will be represented by OWL. Finally, the ontology proposed will be verified through the case addition and system construction.

	Classification	definition/characteristics	Example
Crisis know-ledge	Static know-ledge	Knowledge that does not change with any factors	Emergency knowledge: emergency plans, laws and regulations, etc.
			Emergency platform: National emergency platform, local emergency platform, military emergency platform, etc.
			Main departments: government departments, schools, scientific research institutions, news broadcasters, etc.
	Dynamic knowledge	Knowledge that changes due to the trigger of external influencing factors	Key infrastructure: communication system, transportation system, etc.
			Emergency human resource allocation: experts, military, armed police, professional rescue teams, etc.
			Other emergency resources: life supplies guarantee, emergency shelter, emergency financial resources distribution, emergency medical rescue, etc.

Table 2. Static and dynamic identification of crisis knowledge.

3.1 Pre-reconstruction stages of fine-grained crisis knowledge ontology

3.1.1 Knowledge collection and identification of dynamic attributes

In this study, the crisis knowledge generated in the process of crisis management is selected as the target domain for ontology reorganization. The concept of crisis knowledge and the collection of domain terms are not only an important part of information reorganization but also the basic work of ontology construction. The ways to obtain the concept of crisis domain in this study are as follows: professional books, internet resources, and other ontology models which could offer crisis knowledge. The crisis knowledge is classified according to the general emergency plan of the "public events of the state" and the "emergency platform system information resource classification" (Ryoo and Choi 2006). It should be emphasized that in this section, the data we collect mainly include crisis terms and common concepts, not specific case data.

According to the characteristics of crisis sources, such as wide sources, complex structure, and dynamic changes, the classification and identification of crisis knowledge are carried out from the static and dynamic angles (seen in Table 2). Static knowledge represents the knowledge that does not change with any factors throughout the development of the crisis, like the time when the crisis started and the location where the crisis happened. This kind of crisis knowledge is an objective fact, which is continuous and unchangeable. Dynamic knowledge indicates the knowledge that is under a certain stage of crisis development. Some crisis knowledge also changes due to the trigger of external influencing factors, which are multi-phase and discontinuity, such as the number of casualties in crisis events.

3.1.2 Analysis of crisis knowledge based on temporal-spatial factors

After identifying the static and dynamic crisis knowledge, the temporal-spatial attributes of crisis knowledge will also be analyzed and enriched. For static knowledge, the corresponding time and space attributes are simply labeled and added, because its characteristic attribute is a fixed value, while no additional operation is required. However, for dynamic knowledge, the characteristic attributes are more complex. Each property at different stages and scenes has different values, so it cannot be described like static knowledge. First, time series could be divided into multiple time regions with short duration and high granularity. The life cycle theory (Reuter et al. 2014) is used to represent the time zone change of crisis development including crisis occurrence time zone, crisis development time zone, crisis response time zone, and crisis recovery time zone. Then the concepts of time point, duration, and time units are used to describe the time attributes such as the start and end points of dynamic crisis knowledge. Second, space could be similarly divided into multiple scenes with small space and high density. The division of regional disaster levels (Saoutal et al. 2014) is applied to indicate the severity of disasters in a fixed area. Spatial attributes such as the starting and arriving location of dynamic crisis knowledge are expressed by using spatial coordinates and geographical concepts.

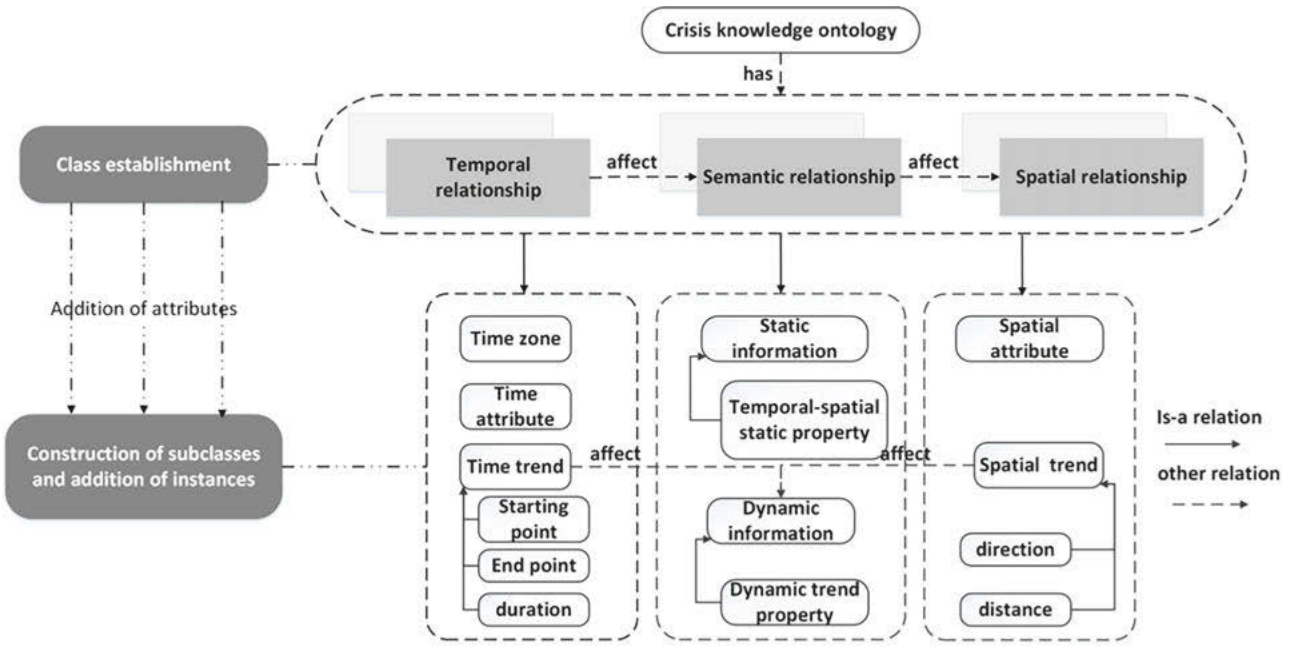


Figure 2. Fine-grained crisis knowledge reconstruction model.

After the division of time series and spatial regions, composite analysis and integration study on temporal-spatial characteristics are also performed. The composite analysis explores the interaction between temporal and spatial characteristics. For example, the division of time zones could affect the regional division of disaster levels. More specifically, in the same disaster area, the severity of disasters must be different in the crisis development time zone and the crisis recovery time zone. Therefore, it is obvious that the joint analysis of temporal and spatial characteristics has an impact on the organization of crisis knowledge. For example, the division of time zones and disaster levels is used to determine whether a region has been affected by a crisis, meanwhile they are also used to determine whether this region is an area of crisis rescue or crisis supply. In turn, crisis knowledge for rescue and supply requires the attributes such as time points and space location to be characterized. Therefore, the characteristics of temporal-spatial and crisis knowledge organization could be mutually promoted and integrated progressively under this method.

3.2 Fine-grained crisis ontology reconstruction

In the previous research of crisis ontology construction, most of them were based on the classification of crisis knowledge contents and concepts. Less attention was paid on the changes of the characteristics and organization of crisis knowledge. Therefore, in this section, we proceed from the dynamic characteristics of crisis knowledge and build up a fine-grained ontology at the feature-level.

The changing features of crisis knowledge are mainly characterized by the time series and space position, which are presented by temporal relationship and spatial relationship separately. At the same time, with the change of temporal-spatial characteristics, the classification and organization of crisis knowledge and related concepts are also constantly updating, which will be presented at the semantic level. Therefore, the fine-grained reorganization of crisis knowledge based on the temporal-spatial perspective is mainly realized by three parts of temporal relationship, spatial relationship, and semantic relationship as mentioned before. The temporal relationship and spatial relationship are used to describe the factors of crisis knowledge while the semantic relationship is used to indicate the dynamic organization of crisis knowledge. For example, during the crisis development, the change of temporal and spatial relationships may lead to the transformation, spread, and derivation of knowledge, which could result in new semantic relationship.

Therefore, according to the temporal-spatial characteristics of crisis knowledge, the conceptual structure of crisis knowledge ontology is proposed. The structure, concepts, and involved attributes of the fine-grained ontology model were shown in Figure 2 (seen in Figure 2). A new structural framework is constructed by using the tool Protégé in order to verify this conceptual model. In this section, the specific steps of fine-grained ontology reconstruction will be illustrated.

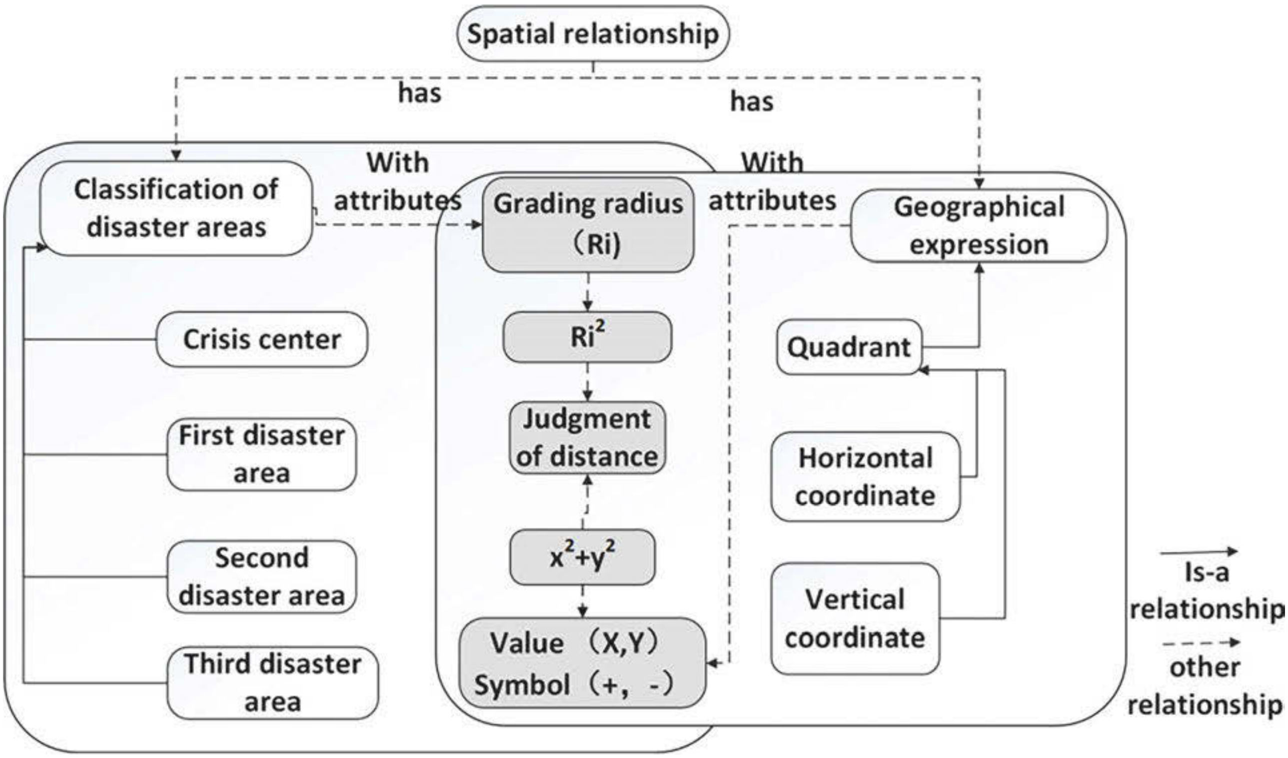


Figure 3. Fine-grained knowledge reconstruction—Spatial Relationship.

3.2.1 Class establishment at the concept

3.2.1.1 Establishment of the Time Relationship class for the fine-grained crisis knowledge ontology

In the reorganization of crisis knowledge, Temporal Relationship is used to describe the time attribute of knowledge and the changing trend of time series, which is mainly expressed by the concepts of time period, time length, time points, etc. The life cycle in the process of crisis management can be divided into four periods, including crisis occurrence, development, response, and recovery. During the period of crisis occurrence and development, the region was at a stage from stability to destruction. Every lifeline has been destroyed. People were injured and a huge amount of crisis information was generated and updated rapidly. Afterwards, in response to the sudden crisis situation, the community will carry out emergency rescue. At this time, the region is at a destructive and stable response phase; the relevant members of the rescue department will dispatch personnel and repair the lifeline. Gradually, the production and living of the area were approached before the crisis, which means the life cycle process of crisis management ended. In each, time period, time point, and duration are mainly used to describe the beginning, ending, and duration of crisis information and emergency rescue. Time points include the related concepts of time units according to each stage during crisis management such as year, month, day, etc.

3.2.1.2 Establishment of the Spatial Relationship class for the fine-grained crisis knowledge ontology

In the reorganization of crisis knowledge, Spatial Relationship is used to describe the spatial attributes of collection and changing trend of geographical location, which are mainly represented by the concepts of spatial entities, disaster regional classification, quadrant, and coordinates (seen in Figure 3).

When the crisis occurs, the specific geographical location is represented by the concepts of province, city, district, street, etc., in the spatial entity. Then, taking the place of the crisis as the center of a circle, the surrounding area is specified into varied disaster grades according to the specific evolution of the crisis. First of all, taking R1 as the smallest radius, the first-order circular area is recognized as the worst affected area. Within this area, various lifeline projects, building construction, and traffic roads are seriously damaged and the amount of the casualties is quite large, so it belongs to "emergency rescue area." As the distance increases from the center of the crisis, the degree of damage to the crisis gradually decreases. Then taking R2 as the radius (R2>R1), the center of the circle remains the center point of the crisis while the secondary circular area with more serious damage will be identified. In this area, buildings that suffered less destruction and victims with fewer wounds could be found when compared with the first-order circular. There are even some roads and people who have not yet been affected by the crisis. To a certain extent, this area has self-rescue and resilience, so it could be regarded as the "key rescue area." Finally, with R3 as the radius (R3>R2), a slightly affected third-order circular area could be identified. Within this region, only a few buildings and people are affected by the crisis, thus it may be considered as the "less-key rescue area." According to this calculation method, the area outside the third-order circular area (R > R3) is out of the danger area. The lifelines and transportation systems are not affected by the crisis, so that no rescue needs to be conducted for this area. It should be noted the values of R1, R2, R3 and the division of circular disaster areas depend on the specific crisis accident. For example, for a traffic accident at a local place, the values of R1, R2, and R3 are all small. Otherwise, the values of R1, R2, and R3 will become larger in a wide range of crisis events, such as fires and earthquakes.

In the representation of Spatial Relationship, coordinates are used to show the geographical location and change trends of crisis knowledge. The Cartesian coordinate system is established with the occurrence point of the crisis event as the center of circle, where the X axis is in the east direction, and the Y axis is in the north direction. The location of important life points in crisis areas (hospitals, schools, residential areas, fire brigades, etc.) is marked in the form of coordinates (x, y). The symbol of the coordinate refers to the geographical orientation of the crisis rescue and supply points while the value of the coordinate represents the distance (in meters) from the center of the crisis. The division of three disaster regions and coordinates of crisis points are both centered on the crisis occurrence point in order to be superimposed through a spatial relationship. Thus, relied on the comparison between geographical location and three order circular division, the level of disaster area for a certain crisis point could be judged.

3.2.1.3 Establishment of the Semantic Relationship class for the fine-grained crisis knowledge ontology

In the reorganization of crisis knowledge, Semantic Relationship is applied to indicate the dynamic identification of crisis knowledge by using temporal-spatial factors (seen in Figure 4). The establishment of Semantic Relationship is supposed to provide semantic services for adding static background knowledge and identifying dynamic evolution knowledge during crisis collaboration.

Static background knowledge aims to describe the knowledge under a stable status before the crisis occurred. It includes political background knowledge (provinces and cities, distribution of important lifelines such as hospitals, schools, and others), economic background knowledge, population background knowledge (urban population, dense residential areas, etc.), traffic background knowledge (main transportation hub), as well as the specific time and location of the crisis. The dynamic evolution knowledge covers rescue demand knowledge and rescue supply knowledge. Rescue demand mainly contains disaster rescue, road traffic rescue, and housing construction rescue. Rescue supply involves economic supply, material supply, manpower supply, and medical supply.

The geographical position of each crisis points could be well represented through the spatial coordinates. After that, we need to judge whether the point is the rescue demand point or the rescue supply point by comparing the straight distance. For example, a hospital is located at the coordinates of (x, y). If $x^2+y^2<R1^2$ (R1 is the radius of the first-order area), the hospital will be regarded under the status of serious damage and cannot provide any medical rescue, therefore it can only be used as a point of rescue demand. If $x^2+y^2>R3^2$, this hospital could be considered as unaffected by any sudden accident, thus it will be set as a medical supply point. However, when $R1^2<x^2+y^2<R2^2$, it is required to determine whether the hospital can offer medical assistance according to the actual extent of the disaster.

3.2.2 Object and data property addition for the fine-grained crisis knowledge ontology

After defining the relationship of the class and its hierarchy, the properties of the crisis concept should be described. Property could be applied to describe the relational properties and subclasses will inherit all the properties of the parent classes. There are two kinds of attributes. One is the object attribute, which correlates the Temporal Relationship, Spatial Relationship, and Semantic Relationship. For example, rescue supply knowledge has the characteristics of supplier, actor, time, place, etc. The other is data type attribute; it supplements the type value that describes the crisis factors. For example, the data property of rescue demand knowledge is characterized through the number of casualties, the number of house damage, etc.

According to the temporal, spatial, and semantic relationships of crisis knowledge, this study defines a variety of important object and data attributes. Examples of domain and value fields are shown in the following table (seen in Table 3).

The OWL-DL ontology model (Allemang and Hendler, 2009) is applied to provide graphical representation for the crisis knowledge ontology. This way of ontology visualization is conducive to reading and understanding, because it

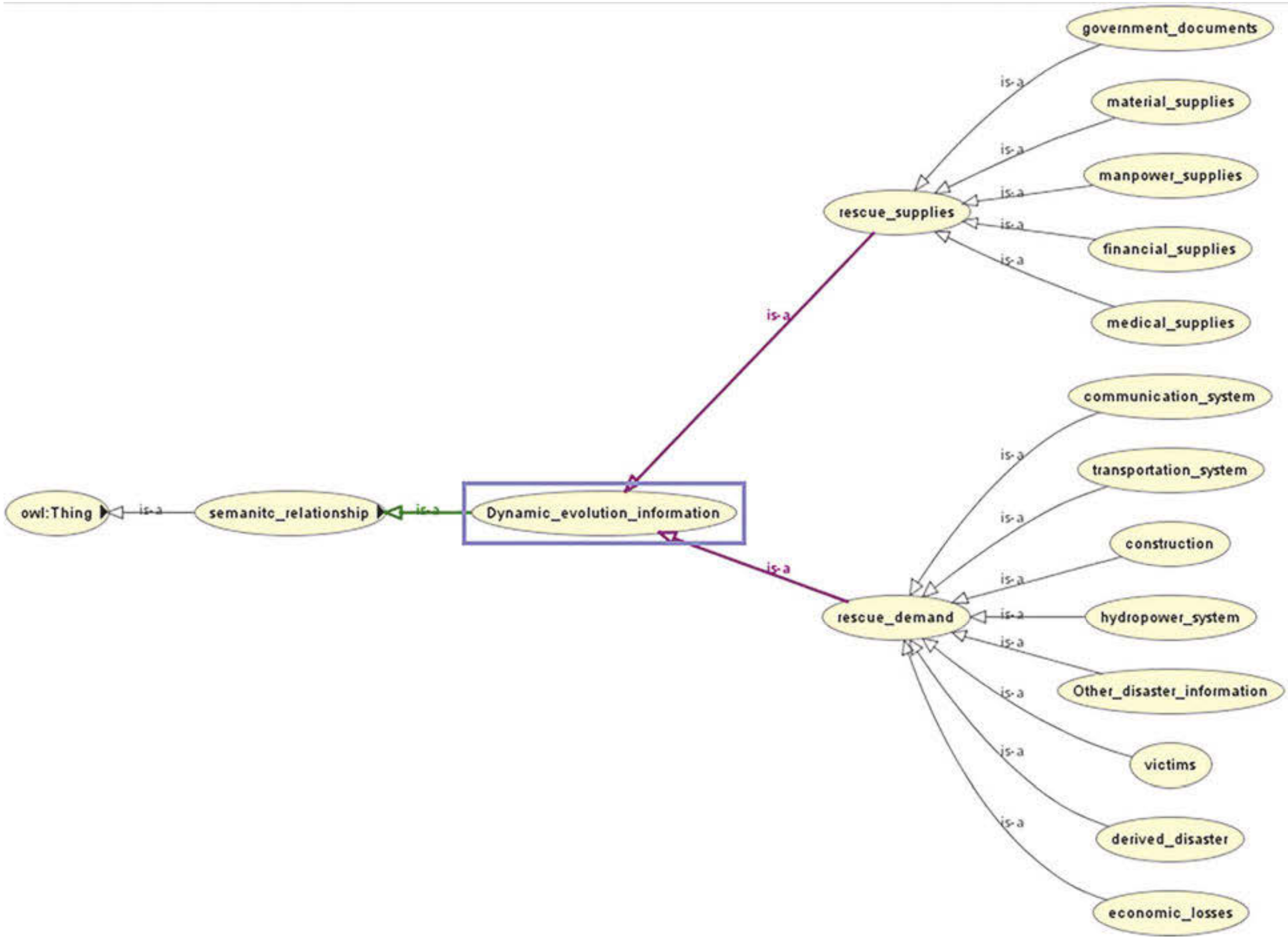
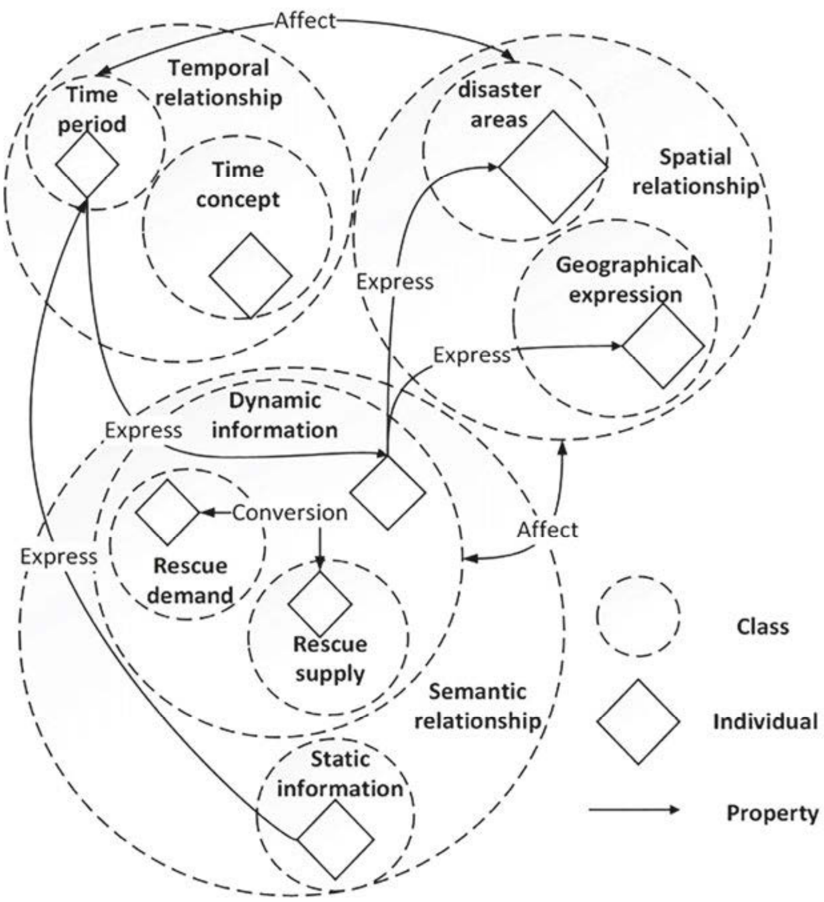


Figure 4. Visualization of semantic relationship.

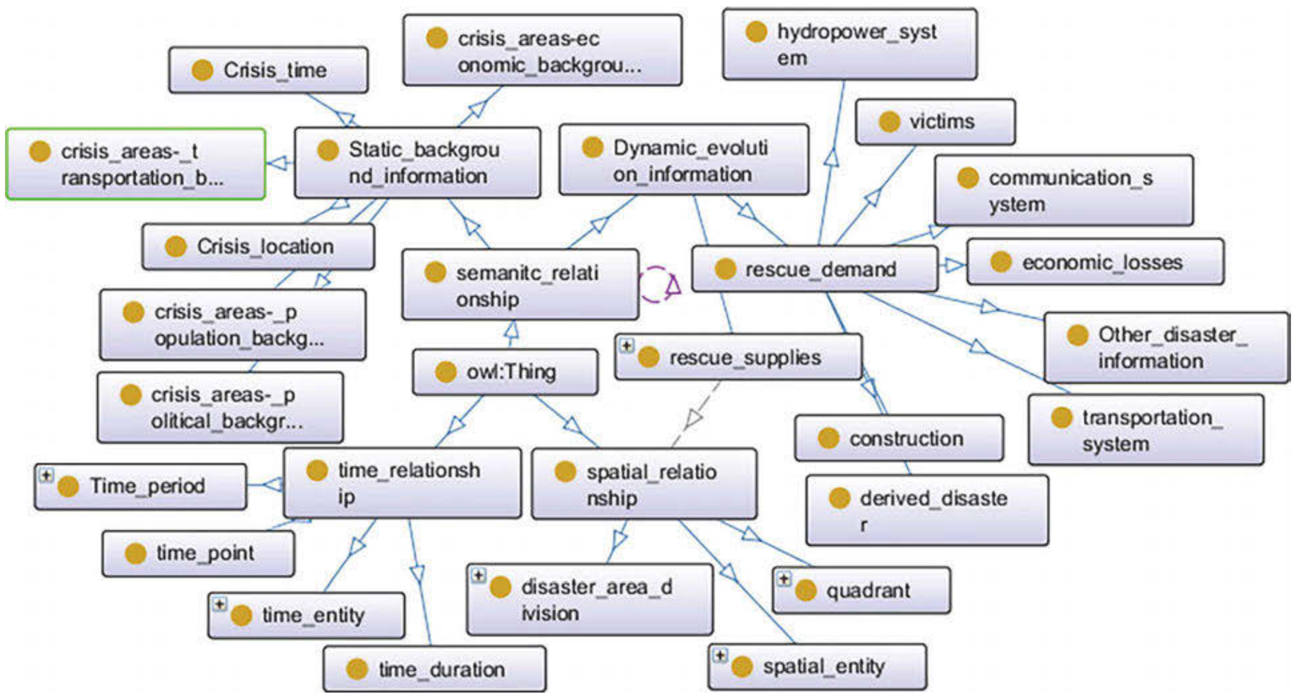
Property	Domain	Range	Property type
Located in	Semantic-relationship	Spatial-relationship	Object property
Belong to	Semantic-relationship	Time-relationship	Object property
Arriving at	Rescue-supplies	Spatial-relationship	Object property
Starting from ……	Rescue-supplies	Spatial-relationship	Object property
Crisis name	Crisis event	String	Data property
Impact building	Rescue-demand	Int	Data property
Impact people	Rescue-demand	Int	Data property
Impact region ……	Rescue-demand	Int	Data property

Table 3. Property example.

can intuitively and clearly express the ontology class, properties, and individual relationship. As shown in Figure 5, the circle refers to the class and the diamond shape indicates the individuals of the class. In addition, the relationship between parent class and subclass is represented by the nesting of circle while the property is visualized through the connecting line between individuals



(a)



(b)

Figure 5. Different representations of the ontology structure.

4.0 Case-based ontology verification

After the construction of ontology model, an effective method should be taken to verify and evaluate it. Ontology model verification methods widely used by researchers mainly include expert evaluation method (Ahmad et al. 2019), qualitative evaluation method (Bannour et al. 2019), quantitative evaluation method (Kaewboonma et al. 2018), and system verification method (Zhang and Xu 2011). Through the comparative evaluation of different methods, combining with the content of this research, we chose the method of systematic verification to evaluate our ontology model. In this section, there are two main steps: 1) case selection and data addition; and, 2) case realization based on the system.

In view of the fine-grained crisis knowledge ontology model based on the temporal-spatial composite analysis proposed in the previous section, in this section a traffic accident case is selected for ontology verification. After comparing the completeness of the data and the detail of the report, the "major traffic accident of rear-end collision" of the Ridong Expressway in Jining City, Shandong Province is selected as the case. At the stage of the accident, multiple vehicles collided in succession, which caused damage to the transportation system and some casualties. In addition, the accident was accompanied by a derivative crisis such as fire and explosion. The local rescue department quickly departed from the accident center and spread out to determine the nearby rescue resources, equipment, and personnel. Then they quickly formed an expert consultation group, emergency rescue group, information communication group, logistics support group, and wounded rescue team for rapid emergency response. The schematic diagram of the ontology relationship of this case is characterized in Figure 6 (seen in Figure 6).

After case selection and data collection, we designed a crisis collaboration system (seen in Figure 7). On the one hand, time information and space information are presented at the same time so users can obtain relevant temporal-spatial information in real time based on the interactive interface. Users can freely select time progress and space location by clicking on circles of different colors and shapes and the time axis, and view the crisis knowledge under the temporal and spatial characteristics. On the other hand, based on this interface, communication and collaboration between different users are allowed. The display and retrieval of crisis time and space knowledge and the interactive communication of crisis users can all be satisfied.

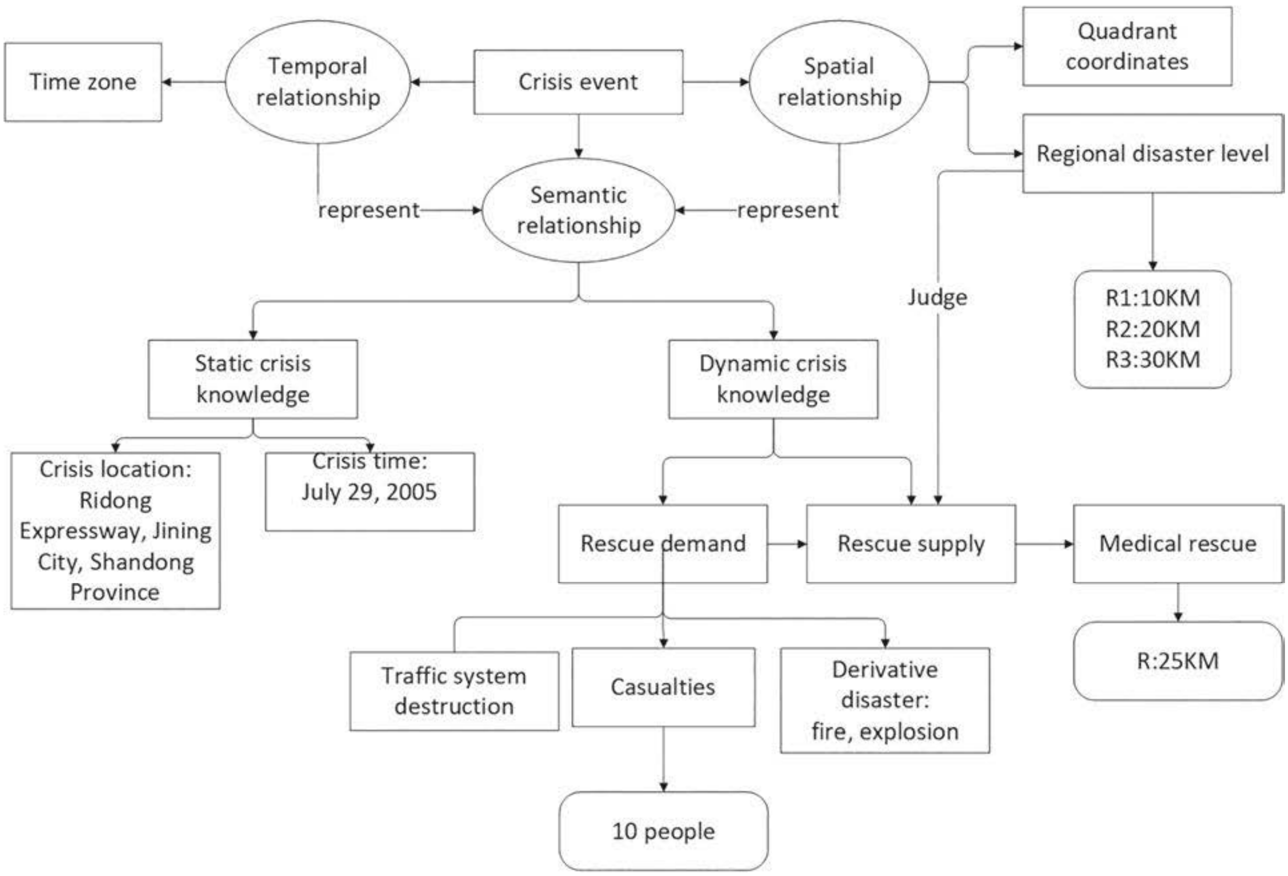


Figure 6. Ontology case representation.

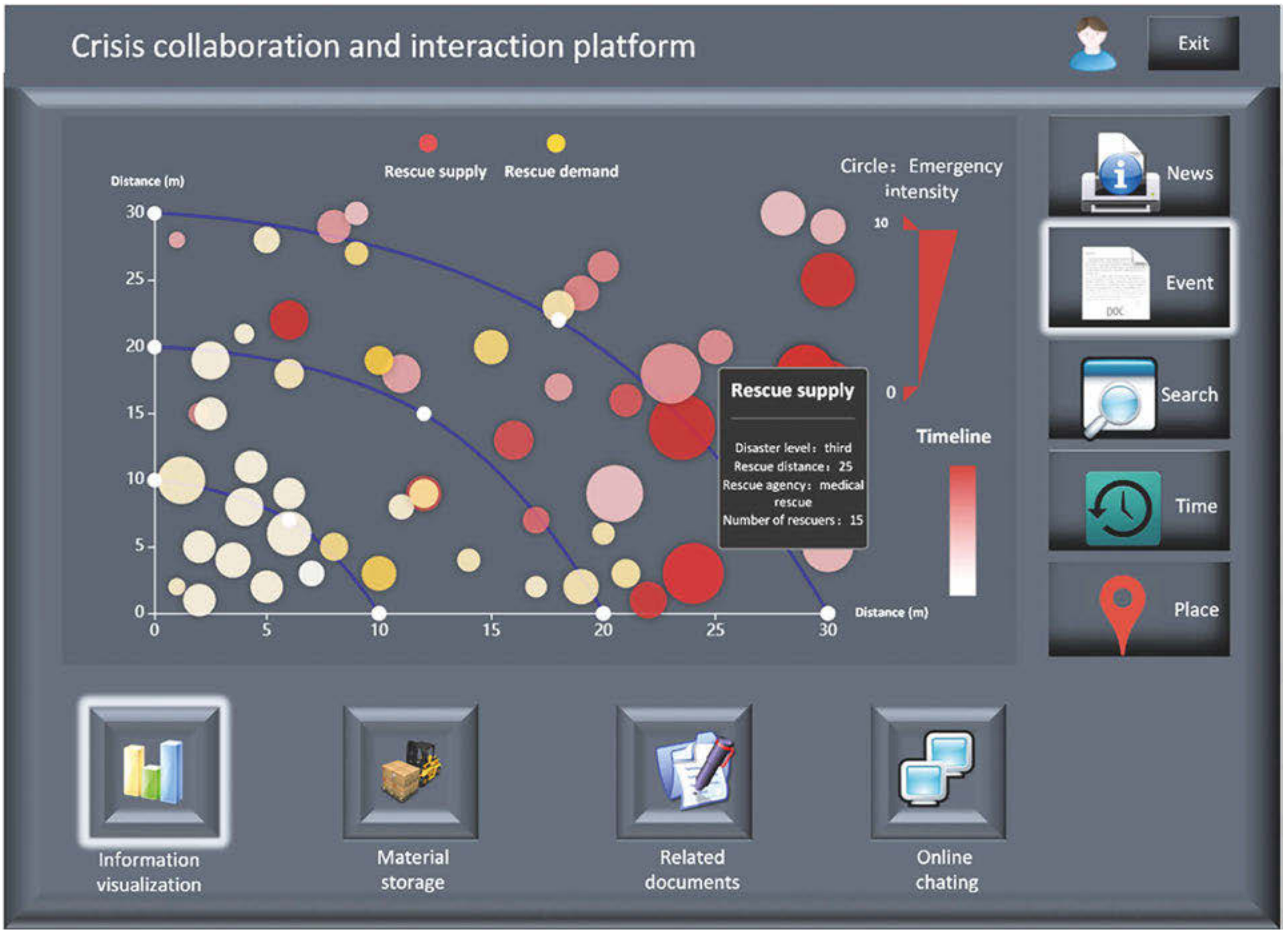


Figure 7. Information interactive interface display.

In the fine-grained ontology proposed in this study, we have emphasized the conceptual relationships at the level of temporal-spatial attributes and semantic relationships based on changes in temporal-spatial factors. Through the construction of cases and query of crisis knowledge, this ontology model proves that it could fulfill its purpose according to the specifications. Meanwhile this fine-grained ontology is able to deal with the context intended for, thereby addressing other aims and objectives. Specifically, the ontology can not only realize information retrieval at the semantic level but also achieve matching and query at the level of temporal-spatial characteristics. Therefore, reconstruction of the fine-grained crisis knowledge ontology model provides effective support for exchange, sharing and reuse of case data and case knowledge.

5.0 Discussion

According to the cross-composite analysis based on the temporal-spatial features and discussion of a construction method, process, and verification on the fine-grained crisis knowledge ontology, it can be seen that the ontology construction model proposed in this study can give a more accurate account of crisis knowledge from its dynamic and static attributes and the organization structure, thus flexibly demonstrating the changing process of semantic relationships in the process of crisis development.

This ontology model accords with the characteristics of real-time collaborative crisis management under the environment of big data, which offers emergency rescue dynamic data and improves the accuracy and credibility of crisis decision making, and provides ideas and methods for the construction of a crisis knowledge base and smart crisis management system in practice.

5.1 Cross-composite analysis method based on the characteristics of temporal-spatial helps crisis knowledge expression more accurate (answer to RQ 1)

The temporal-spatial composite analysis method of crisis knowledge conforms to the characteristics of dynamic crisis management under the environment of big data and AI. From the view of temporal-spatial factors connecting and interacting together, the dynamic attributes of crisis knowledge are clearly stated, and the changing trend of crisis knowledge and temporal-spatial characteristics are discussed in depth, which provides an important theoretical basis for real-time crisis management. Firstly, cross-composite analysis method based on temporal-spatial characteristics enriches the types and attributes of crisis knowledge. Specifically, the original classification of crisis knowledge based on the crisis category or the crisis situation is perfected by the analysis from the perspective of dynamic features of temporal-spatial, which adds the dynamic description based on temporal-spatial relationships and enriches the knowledge types and attributes in a crisis management system. For example, static crisis knowledge represents the knowledge that does not change with time and space in the process of crisis development, including the fixed attributes such as place and time in crisis incidents. Dynamic crisis knowledge, on the other hand, represents the knowledge with multi-stage and discontinuous attributes, such as the number of real-time casualties in crisis events. Therefore, the classification and analysis of crisis knowledge are no longer just an extension of crisis types but a composite result based on whether knowledge is influenced by temporal-spatial factors.

Besides, cross-composite analysis method based on temporal-spatial characteristics improves the accuracy of crisis knowledge management. The division and cutting of time series and space scenes improves the precision and density of crisis knowledge management, and the deep and concrete knowledge expression flexibly records the information changing trend, providing the feasibility for real-time crisis management. For instance, time zone in the whole process of crisis, according to the life-cycle theory, can be divided into occurrence time zone, development time zone, response time zone, and recovery time zone. Similarly, spatial scenes are divided into multi-scenes with small space and high density. In addition, the cross-impact analysis between fine-grained time fragments and spatial scenes, reveals some potential and hidden knowledge, as well as neglected knowledge association models and rules. However, the discovery of these problems at the same time provides the important basis for real-time crisis management and contributes to decision making and prediction in smart crisis management.

5.2 A fine-grained crisis ontology model enhances the structure flexibility of crisis knowledge (answer to RQ 2)

From the perspective of temporal-spatial, a fine-grained crisis ontology model realizes the dynamic and flexible reconstruction of knowledge. At the same time, the fine-grained ontology construction at the feature-level represents more accurately the dynamic features and trends of crisis knowledge. As crisis knowledge retrieval and matching can be realized from the perspective of temporal-spatial characteristics and semantics; the ontology reuse and updating and knowledge navigation become more convenient, and efficiency of complex relationships retrieval is improved, which provides ideas and methods for semantic retrieval and reasoning on the big data platform.

A fine-grained crisis ontology solves problems such as semantic conflicts and semantic ambiguities and realizes the effective sharing of knowledge structure. First, the ontology construction avoids conceptual and terminological confusion in different fields, making common understanding and communication possible. Secondly, the study of a fine-grained crisis knowledge ontology starts from three aspects: temporal relationship, spatial relationship, and semantic relationship, which through logic reasoning accurately describes both the conceptual meaning and the internal relation between concepts. With the strong ability to express conceptual meaning and acquire knowledge, the problem of semantic heterogeneity can be fundamentally solved.

The fine-grained crisis ontology extracts the knowledge organization module from a crisis management system, theoretically, and adjusts the original structure by using the cross-composite analysis in the temporal-spatial dimension. Therefore, the framework of crisis knowledge is not a simple integration of knowledge types any longer but a dynamic reconstruction constrained by conditions on time and space in real-time emergency rescue. Specifically, based on a temporal-spatial characteristic unit, the ontology model analyzes the changes of crisis knowledge and semantic relations under the joint action of spatial-temporal in different stages of crisis management so as to optimize its organizational structure. This dynamic organization takes the actual situation in different stages of crisis rescue into full consideration so that crisis users can obtain the latest crisis knowledge in time. Meanwhile, the relationship and attributes between different crisis knowledge are also clear at a glance, enabling users to search and query accurately and quickly.

5.3 A fine-grained crisis ontology model improves synergy in crisis management

The cross-composite analysis method of temporal-spatial characteristics and the fine-grained crisis knowledge ontology construction based on feature units provide new ideas and methods for real-time management and collaboration in crisis. The results show that this method can effectively solve problems like singleness of organizational structure, static hysteresis of information, and low efficiency of communication and sharing, offering an important reference for accurate and timely decision-making. Besides, by this method, crisis knowledge base of temporal-spatial characteristics can also be constructed to provide not only the real-time dynamic data for a crisis management system but also a platform for real-time interaction and knowledge sharing of crisis users, improving the efficiency of emergency response in all directions.

The study focuses on the attribute in the temporal-spatial dimension and how it regularly changes. It makes the structure and transmission of crisis knowledge not merely a static summary but a constantly dynamic organization, which reflects crisis state and management at different time nodes and geographical locations. This dynamic structure can realize the cooperation of crisis users, promote effective information exchange, knowledge release and sharing, and the formulation of rescue policies.

Furthermore, a fine-grained crisis knowledge ontology model can be directly applied to platform design and implementation in crisis knowledge sharing and collaboration. The shared conceptual model in the whole emergency response field, constructed on the basis of a crisis knowledge ontology model, can eliminate semantic ambiguity, unify heterogeneous data sources from different departments, and then share a common understanding of decision-making, which eventually realizes synergy in emergency management of various departments and different crisis roles and improves the efficiency of emergency command and management.

6.0 Conclusion

In this paper, we propose a temporal-spatial analysis method for the crisis knowledge organization. A fine-grained crisis knowledge ontology was conducted from the feature-level, which could accurately express the temporal-spatial dynamic attributes and changing trends of crisis knowledge. Furthermore, a crisis case was adopted as well to verify this crisis ontology model.

The restructuring of crisis knowledge based on the temporal-spatial features is supposed to have profound theoretical significance and application value. From the theoretical aspect, this study selects the knowledge organization module from the emergency management system and adjusts the original organizational structure in the temporal-spatial dimension. Simultaneously, it solves the problems caused by inflexible structure and lack of dynamic integration in crisis knowledge organization. The knowledge of the crisis management will be accurately refined and described according to deeper analysis of dynamic characteristics. From the practical aspect, this study may provide a new idea for the dynamic and collaborative decision-making in the crisis management and system design, which emphasizes the progressive changes on the knowledge attributes and flexible knowledge association during the development of crisis. Meanwhile, it will also make some suggestions for the intelligent emergency management and smart city construction by illustrating the reference and providing support for social management ability and decision-making practice. In the next stage of research, we are going to focus on the dynamic information requirements of users in crisis information management to renew and improve the functions of the current model.

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