Pattern-Based Ontology Modeling andReasoning for Emergency System

Yue TAN†, Wei LIU†(a), Zhenyu YANG†, Nonmembers, Xiaoni DU††, Member, and Zongtian LIU†, Nonmember

SUMMARY Event-centered information integration is regarded as one of the most pressing issues in improving disaster emergency management. Ontology plays an increasingly important role in emergency information integration, and provides the possibility for emergency reasoning. However, the development of event ontology for disaster emergency is a laborious and difficult task due to the increasingly scale and complexity of emergencies. Ontology pattern is a modeling solution to solve the recurrent ontology design problem, which can improve the efficiency of ontology development by reusing patterns. By study on characteristics of numerous emergencies, this paper proposes a generic ontology pattern for emergency system modeling. Based on the emergency ontology pattern, a set of reasoning rules for emergency-evolution, emergency-solution and emergency-resource utilization reasoning were proposed to conduct emergency knowledge reasoning and q.

key words: emergency system, event ontology, ontology pattern, reasoning rules

1. Introduction

In recent years, the high-frequency public emergencies have received considerable attention and high regards from researchers across many disciplines (geography, sociology, information and knowledge system). It is a novel approach to analyse and reasoning emergencies based on big data of event-centered information. However, due to the trans-regional semantic conflicts and the considerable disparities of information technology [1], there still exist multiple problems of information interchange and data integration related to public emergency events [2]–[5].

Ontology has acquired wider significance in semantic interoperability of emergency data interaction. Particularly, the event ontology surpasses traditional concept ontology in various aspects [6] have been proved by plenty of studies on event and event-centered ontology [7]. However, the development of emergency events ontology is always a laborious and difficult task because of the diversity and complexity of emergencies. To simplify the development of ontology, it is critical to reuse the existing ontology engineering results. The ODP (Ontology Design Pattern) provides a reusable solution to the complicated modeling problems. Blomqvist, Sandkuhl [8] and Gangemi [9] introduced the ODP concept and the idea of reusing existed patterns to simplify the ontology development, and realize a well-designed content pattern which can be reusable in many different application contexts [10]. Furthermore, a prototype ontology can be extended through the prototype-plan (P-Plan) studies in [11], thus a complete event content ontology pattern should not only contain the fundamental event element information, but also consist of all derivative events and its flow description, including the process flow and closure operation.

In this paper, we extend the existed event model in [12]–[14] based on numerous case studies of emergencies, propose a generic content ontology pattern for emergency system, which could be reused to develop specific ontology quickly. The pattern describes a general emergency with two modules, emergency occurrence and emergency response. The emergency occurrence module was modeled as a complete event flow [15], including event occurrence, processing and closure, and the response module gives the corresponding emergency response measures. The pattern provides a general reasoning knowledge base with a set of general reasoning rules for Emergency-Evolution (e.g. River Pollution → Ecological damage). Emergency-Solution (e.g. River Pollution → Sewage disposal) and Emergency-Resource-utilization (e.g. River Pollution → Install monitoring equipment), so as to support quick response of emergency. In addition, we present generation methods for reasoning rules through the similarity calculation, moreover, provide a case study of reasoning verification.

The remainder of this paper is organized as follows. Section 2 introduces the concepts about emergency event model and event ontology design pattern. Section 3 describes the modeling of emergency event ontology pattern. Section 4 gives three types of reasoning methods involved in the emergency event ontology pattern built in Sect. 3. Finally, Sect. 5 concludes by summarizing our results and pointing out directions for future work.

2. Background of Emergency Event Ontology Pattern

2.1 Emergency Event

This section describes the definition and the representation model of emergency event.

Definition 1. Emergency Event: The public emergency is an unexpected and difficult or dangerous situation, especially an accident, which happens suddenly and cause serious casualties, property damage, ecological environment destruction and serious social harm or endanger public safety.
It requires quick action to deal with. Such as earthquake, terrorist attack, etc.

The emergency event in this paper are natural disasters, accident disasters, public health events and social security events that occur suddenly, cause or may cause serious social harm, and need a series of emergency measures.

According to the definition of events in [16], the emergency events can be defined as a 6-tuple formally:

\[
\text{Emergency Event}_{\text{def}} := \langle A, O, T, P, R, F \rangle
\]

We call elements in 6-tuple as emergency event elements. Where \( A \) indicates a set of actions happen in an emergency event. The action is usually used to recognize an event; \( O \) means event objects, including two types of actors involved in event, the action initiators named object and the action receiver named subject. \( T \) means the duration of event, it can be represented as absolute time and relative time. \( P \) means the event location, it can represent the physical place (such as Shanghai, 108 National Road) and the cyber space place (such as at home, online). \( R \) refers to the resources involved in events, it is composed of human resource, material resource and social resource. Human resource refers to the manual labor involved in the event, such as rescue workers, investigation agencies, etc.; Material resource indicates the necessary rescue equipment, economic support and so on; Social resource refers to the public opinion or public activities (such as the activities of mourning for the dead in the mass shooting event). \( F \) denotes the influencing factors of emergency events, all kinds of events have their specific influencing factors, \( F \) could be human factor, natural factor or social factor. Human factor is the human behavior that causes the emergency (such as the discharge of sewage in the water pollution event); Natural factor refers to the environmental reason which lead to emergency occurrence, including geographical situation, regional characteristic and weather condition; Social factor like equipment security risks, technical restrictions which can result in the emergency event. Among the six elements of the emergency events, the element \( A, O, T, P \) are core elements of event, \( R \) is the event resource element, and \( F \) refers to the event factor element. The model of emergency event structure is shown in Fig. 1.

2.2 Emergency Event Class & Ontology

**Definition 2. Emergency Event Class:** Emergency Event Class is a type of event that represents a set of emergency events with some common characteristics, denoted as EC:

\[
EC = (E, C_A, C_O, C_T, C_P, C_R, C_F)
\]

\[
C_i = \{c_{i1}, c_{i2}, \ldots, c_{im}, \ldots\} \ (i \in \{E, O, T, P, R, F\}, m \geq 0)
\]

Emergency Event Class is composed of the \( E \) and \( C_i \). Where \( E \) means an emergency event set, is called extension of the emergency event class. \( C_i \) is the set of event elements, called intension of the emergency event class. It denotes the common characteristics set of certain emergency event element (element), \( C_{im} \) denotes one of the common characteristics of emergency event factor i. \( C_{im} \) is also called emergency event elements class.

**Definition 3. Emergency Event Ontology:** An emergency event ontology is a shared, formal and explicit specification of an emergency event class system model that exists objectively. Emergency event ontology \( EO \) can be defined as a 3-tuple formally:

\[
EO = (ECs, R, Rules)
\]

Where \( ECs \) is a set of emergency event classes; \( R \) is a relation set, we define five event relationships, subsumption relation (is_a), composition relation (is_composed_of), causality relation (cause), follow relation (follow) and concurrency relation (concurrency); \( Rules \) is set of rules be expressed in logic languages, describes rules for event-class-evolution, emergencies-solutions and resource-utilization reasoning. These rules were originally built on the emergency event ontology, and the rules were continually enriched in the continuous learning process of the emergency event ontology.

2.3 Event Flow

**Definition 4. Event Flow:** Event flow [15] means the whole process descriptions of occurrence of an emergency event, including occurrence, processing and closure, which creates interconnections of different development stages, different processes, potential derivative events and relevant resources of emergency event.

The descriptions of a complete event flow enable comprehensive knowledge representation of emergency-evolution, emergency-solution and emergency-resource utilization. And most of the emergencies process can be represented as the complete event flow.

2.4 Ontology Design Pattern

**Definition 5. ODP:** The ODP (Ontology Design Pattern) is a reusable solution to recurrent modeling problems [17]. The basic idea of ontology design pattern is highly similar to that of the software design pattern. Specifically, it is a set of ontology elements, structures or development principles used for solving specific ontology engineering problems. The ontology design pattern is reusable and thus can be applied to certain ontology sets through precise duplication or adaptation. Meanwhile, it can appear in the future ontology, as well. The ontology design pattern can improve the quality of ontology design and raise the reusability and maintainability of ontology, which makes it easier to understand ontology [18].
At present, the main ontology design patterns [19] can be divided into logical ODP, reasoning ODP, presentation ODP, content ODP, structure ODP and other types, as is shown in Fig. 2.

Among them, the content ontology design pattern (CODP) is a method proposed by Gangemi and Blomqvist & Sandkuhl [8], [9] in 2005, which is a typical model that implements the instantiation of target ontology or ontology module through the specialization of CODP entity. CODP encapsulates existing ontology into reusable ontology blocks to simplify the complexity of ontology building. This paper uses CODP and eXtreme [20], a related ontology building methods, so that developers can reuse existing ontology to build new ontologies, thus to improve the efficiency of ontology development and avoid some of the most frequent modeling mistakes.

3. Emergency Event Ontology Pattern

In this paper, by using the method of event ontology pattern construction proposed in [21], we develop the upper emergency event ontology pattern based on the specific emergency event ontologies. For instance, we utilize event classes and elements extraction algorithm [21] to extract common parts from a set of specific ontologies, including Water-Pollution event ontology, Air-Pollution event ontology, and Photochemical-Pollution event ontology constantly, and then build an Environment-Pollution event ontology pattern. Furthermore, based on the event ontology pattern of Environment-Pollution, Industrial-Accident and Traffic-Accident, an Accident-Disaster event ontology pattern can be constructed, and then the upper Emergency Event ontology pattern can be generalized from the Accident-Disaster, Natural-Disaster, Public-Health Emergency, and Public-Security Emergency ontology patterns. In this section, we provide a detailed flow description for the Emergency Event ontology pattern.

3.1 Model of Emergency Ontology Pattern

Through the study of a large number of emergencies with text description, we find that the description of an emergency usually contains a set of events related to emergency occurrence and a set of events related to emergency response. The ‘Emergency Occurrence Event’ was modeled as a complete event flow, which can be classified into ‘Emergency Trigger Event’ (including Natural Trigger events and Human Trigger events), ‘Emergency Evolution Event’, ‘Emergency Closure Event’ according the time sequence of events. Accordingly, the ‘Emergency Response Event’ gives the corresponding emergency response measures, which can be classified into ‘Emergency Prevention Event’, ‘Emergency Processing Event’ and ‘Emergency Rehabilitation Event’.

We represent these event sets with emergency event classes, thus all events above constitute a hierarchy of event classes as shown in Table 1. By creating semantics relationship between these event classes, we present a general ontology pattern for describing most emergency system, as shown in Fig. 3.

In the pattern of Fig. 3, there are two top event classes, ‘Emergency Occurrence’ and ‘Emergency Response’, with a causality (cause-effect) relationship between these two top classes. The ‘Emergency Occurrence’ is cause, ‘Emergency Response’ is effect. These two top event classes will be illustrated as two modules in pattern.

### 3.1.1 Emergency Occurrence Module

<table>
<thead>
<tr>
<th>Module</th>
<th>Event Types</th>
<th>Event classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency Occurrence</td>
<td>Trigger Event</td>
<td>Natural Trigger</td>
</tr>
<tr>
<td></td>
<td>Evolution Event</td>
<td>Damage, Casualty, Notification</td>
</tr>
<tr>
<td></td>
<td>Closure Event</td>
<td>Emergency Stop, Restore Order</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Prevention Strategy, Prevention Simulation</td>
</tr>
<tr>
<td>Emergency Response</td>
<td>Prevention Event</td>
<td>Prevention Resources Preparation</td>
</tr>
<tr>
<td></td>
<td>Processing Event</td>
<td>Response Action, Investigation</td>
</tr>
<tr>
<td></td>
<td>Rehabilitation Event</td>
<td>Restoration, Reconstruction</td>
</tr>
</tbody>
</table>

There are three sub event classes inherited from ‘Emergency Occurrence’, ‘Trigger Event’ class, ‘Evolution Event’ class and ‘Closure Event’ class, with follow relationships between two of them, means temporal sequence of these three event classes. ‘Trigger Event’ class represents events that trigger emergency, including Natural Trigger events (such as *earthquake*) and Human Trigger events (such as *explosion*). ‘Evolution Event’ class represents events that happen after trigger events, which are used to describe the process of emergency, including Damage events, Casualty events, and Notification events. ‘Closure Event’ class represents events that means the end of emergency occurrence, including Emergency Stop (such as *hurricane stop in hurricane emergency*, *terrorists be killed in terrorism attack emergency*) and Restore Order (such as *clean-up the scene of emergency*).

According to the definition of emergency event in Sect. 2.1, event class in emergency pattern consists of Event-Factor, Event-Core-Elements (action, object, place and time) and Event-Resource. The Event-Factor describes the pre-conditions of emergency events. For example, in a *traffic accident*, the *brake be out of control*, or *drink driving*. Event-Factor of emergency includes Natural Factor, Human
Table 2  Factor element of emergency event

| Fhuman | The human behavior that causes the emergency event.
|        | e.g. Drink driving in the Traffic accident event |
| Fnatural | The environmental factors that lead to the event occurred, including geographical situation, regional characteristics and weather conditions, etc. |
| Fsociety | The factors like the potential equipment security risks, technical restrictions which can affect the event |

Table 3  Resource element for emergency event

| Rhuman | The manual labor involved in the event
|        | e.g. The rescue workers, police force in the Mass shooting event |
| Rmaterial | The necessary rescue supplies, economic support in the event
|        | e.g. The rescue equipment, emergency supplies, public facilities, etc. |
| Rsociety | The public opinions or public activities in the event
|        | e.g. The media public opinions, activities of mourning for the dead in the Mass shooting event |

Factor and Society Factor, as shown in Table 2.

The Event-Resource describes all the resources involved in the event, which is composed of Human Resource, Material Resource and Social Resource. As is shown in Table 3.

The reusing of event classes in ‘Emergency Occurrence Module’ could speed up the scenario modeling of specific emergency ontology. Section 3.2 will provide an example of reusing the pattern to model river pollution emergency.

3.1.2 Emergency Response Module

There are three sub event classes inherited from ‘Emergency Response’ class, ‘Prevention Event’ class, ‘Processing Event’ class and ‘Rehabilitation Event’ class, with follow relationships between two of them, means emergency prevention follow emergency processing and emergency rehabilitation follow emergency processing. ‘Emergency Processing’ class represents events that organizations concerned process emergency while be notified, it has two sub classes, Response Action class and Investigation class. Response Action includes Emergency Level Evaluation, Emergency Disposal (Resist Disaster, Damage Prevention and Rescue). Investigation represents Government Investigation and NGO-Investigation of emergency. ‘Emergency Prevention’ class represents events that organizations take measures to prevent similar emergencies, with three subclasses, Prevention Strategy (like Risk Analysis and Preventative Improvement), Prevention Simulation (such as fire drill) and Prevention Resources Preparation (like Monitoring Equipment Installation). ‘Emergency Rehabilitation’ class represents events that organizations concerned launch post-emergency rehabilitation, including Restoration (like Public Facilities Restoration, Ecological Restoration) and Reconstruction (such as housing reconstruction, psychological reconstruction of Injured).

By reusing ‘Emergency Response Module’, ontology developer could effectively model emergency response scenario for different specific domain, thus to generate response solution for decision makers quickly.

3.2 An Example: Ontology of River-Pollution

Based on the generic emergency ontology pattern above, the specific domain ontology can be constructed. As a universal subfield emergency case, the river pollution emergency case is exemplified to building a River-Pollution Ontology. Likewise, ontology of other subfields, such as air pollution event or photochemical pollution event, can be established in the same way.

The specific case of River-Pollution emergency can be represented as follows.
Fig. 4  Ontology for river-pollution emergency

Table 4  Description of river-pollution event

<table>
<thead>
<tr>
<th>Event Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - Sewage Discharge</td>
<td>Trigger event</td>
</tr>
<tr>
<td>O - Polluters, River</td>
<td>Discharge time</td>
</tr>
<tr>
<td>T - Discharge time</td>
<td>Polluted drainage area</td>
</tr>
<tr>
<td>P - Polluted drainage area</td>
<td>Discharge of toxic substance exceeds water self-purification capacity</td>
</tr>
<tr>
<td>R\textsubscript{EPA}</td>
<td>Environmental Protection Agency (EPA), Police forces</td>
</tr>
<tr>
<td>R\textsubscript{Media}</td>
<td>Media reports, Public opinions</td>
</tr>
<tr>
<td>F\textsubscript{discharge}</td>
<td>Discharge of Sewage</td>
</tr>
<tr>
<td>F\textsubscript{River}</td>
<td>River pollution treatment mechanisms</td>
</tr>
</tbody>
</table>

As for the River-Pollution Ontology, as Fig. 4, it is composed of two modules: ‘River-Pollution Occurrence Module’ and ‘River-Pollution Response Module’.

The ‘River-Pollution Occurrence’ consists of three sub event classes: ‘River-Pollution Trigger Event’ contains all the event element involved in the Table 4 as the Event-Factor, Event-Core-Elements (action, object, time and place) and Event-Resource; ‘River-Pollution Evolution Event’ describes the derivative events evolved from trigger event, like water quality decline, ecological damage, etc.; ‘River-Pollution Closure Event’ represents the event like water quality index reach standards, pollution cessation.

As for ‘River-Pollution Response’, there are also three sub event classes corresponding to occurrence module: ‘River-Pollution Prevention Event’ propose the corresponding measures: Prevention Strategy (enhance real-time monitoring, risk analysis and control, law of pollution control), pollution control simulation, Prevention Resource Preparation (river supervisor settings); ‘River-Pollution Processing Event’ is decomposed into Response Action, like police pursue, medical rescued, sewage disposal and EPA investigation for the derivative events given in the ‘River-Pollution Evolution Event’; ‘River-Pollution Rehabilitation Event’ is described as punished, health recovery, compensation and ecological restoration.

4. Reasoning Based on Emergency Ontology Pattern

4.1 Reasoning for Emergency Ontology Pattern

The ontology pattern provides a general solution for domain ontology modeling, in addition, the emergency reasoning knowledge base (ERKB) in the pattern provides rules base and guidance for emergency event reasoning in specific domain.

In the previous research [22], rule-based reasoning and case-based knowledge reasoning are widely used in domain of emergency. In this paper, by combing the emergency reasoning rules base, a hybrid reasoning method which consist of Jena2 inference machine and the Pellet inference machine [23] is used for emergency event reasoning. Specifically, the reasoning steps are as follows:

a) Input emergency case information, get the ontology descriptive information in the ontology layer;
b) Activate the OWL DL reasoning functions with the Pellet inference machine: ontology consistency inspection, ontology classification and event classes consistency detection;
c) Perform reasoning through the Jena2 inference machine with the user-defined rules in the ERKB and the data processed by the Pellet inference machine;
d) Output the reasoning results.

As a part of emergency ontology pattern, the ERKB was built to store the user-defined rules used in Jena2 inference machine. In specific domain event reasoning, the corre-
sponding reasoning rules are selected from the ERKB to execute reasoning directly or used as a pattern to create new rules, so as to construct a reasoning knowledge base for specific domains quickly. About how to generate the appropriate reasoning rules in the ERKB, the following steps describes the method of reasoning rules generation based on similarity calculation:

a) Calculate the similarities of event classes and elements in the emergency ontology pattern, analyze the definitions of reasoning rules.

b) Compare the similarity degree in (a) to a specific threshold value, if the similarity degree is higher than the value, link these event classes or elements, represent the evolution relations with high frequency as reasoning rules.

c) Generate the event reasoning rules with the similarity calculation method proposed in the Sect. 4.2.

d) Structure rules in (c) with the formalized method described in the Sect. 4.3.

e) Store the rules in ERKB to support the Jena2 inference machine.

There are various relations among the events in the pattern. According to the different kinds of relations, the user-defined reasoning rules can be classified into Emergency-Evolution, Emergency-Solution and Emergency-Resource Utilization, as Table 5.

<table>
<thead>
<tr>
<th>Rule</th>
<th>Stereotype</th>
<th>Instance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule1</td>
<td>Emergency-Evolution</td>
<td>River Pollution → Biological Community Change</td>
</tr>
<tr>
<td>Rule2</td>
<td>Photochemical Pollution</td>
<td>Building Corrosion</td>
</tr>
<tr>
<td>Rule3</td>
<td>Mass Shooting</td>
<td>Explosion</td>
</tr>
<tr>
<td>Rule4</td>
<td>Fire Prevention</td>
<td>Fire Prevention Practice</td>
</tr>
<tr>
<td>Rule5</td>
<td>Water Pollution</td>
<td>Real-time Monitoring of Water Quality</td>
</tr>
<tr>
<td>Rule6</td>
<td>River Pollution</td>
<td>EPA Investigation</td>
</tr>
<tr>
<td>Rule7</td>
<td>Mass Shooting</td>
<td>Dispatching Police Force</td>
</tr>
<tr>
<td>Rule8</td>
<td>Local Fire</td>
<td>Fire-fighting Equipment</td>
</tr>
<tr>
<td>Rule9</td>
<td>Water Pollution</td>
<td>Shortage of Drinking Water</td>
</tr>
<tr>
<td>Rule10</td>
<td>Nearby Supermarkets</td>
<td>Panic Buying Drinking Water</td>
</tr>
</tbody>
</table>

Table 5 Reasoning rules in pattern

4.2 Generation of Reasoning Rules

The reasoning rules in ERKB are generated by the similarity calculation of event classes and elements. On this basis, if the similarity degree is higher than a given threshold value, the corresponding event classes or elements will be associated as reasoning rules.

4.2.1 Event Similarity Calculation

The similarity calculation of event classes and elements can be converted into a string matching or similarity algorithm. A number of previous studies described the string similarity calculation as two layers [24], namely, syntax similarity and semantic similarity.

In this paper, we calculate the syntax similarity and semantic similarity of different events to get similarity values between event classes or elements. Based on the calculation results, the reasoning rules of high similarity degree events can be formulated.

a) The Syntax Similarity

The syntax similarity is mainly determined by the event elements, while the elements similarity is calculated by the similarity of element linguistic, that is, string similarity of element events. Hence, in this paper, the syntax similarity is calculated according to the character strings similarity of event elements [25].

For event elements arg1 and arg2, the syntax similarity S_{syn}(arg1, arg2) can be calculated according to the formula as follows:

\[ S_{syn}(arg1, arg2) = \frac{2 \cdot \text{Common}(arg1, arg2)}{\text{Len}(arg1) + \text{Len}(arg2)} \]

Among of them, the Common (arg1, arg2) is the number of common words in arg1 and arg2. The Len (arg) represents the length of event element arg.

b) The Semantic Similarity

The semantic similarity calculation requires semantic knowledge and resources. The knowledge base HowNet, which is a common-sense knowledge base that unveils interconceptual relations and concept-attribute relations is used as the source of semantic knowledge in this paper [26]. The description objects of HowNet are the concepts represented by Chinese and English words. It uses a series of sememes to describe each concept and establishes a knowledge base where each vocabulary is represented by a 4-tuple: \(<_W X = \text{the word}, E_X = \text{the word instance}, G_X = \text{the word syntactic}, \text{DEF = concept definition}>,\) where DEF denotes the relation between the word and its sememe that plays the most important part in lexical description, which can be briefly perceived as a word-formation method based on sememes through certain relations.

The formula given in the research [28] was adopted to calculate the semantic similarity S_{sem}(arg1, arg2) of event elements arg1 and arg2. The research proposed a method for calculating the semantic expressions similarity of two concepts expressed in a knowledge-description language, which, to be specific, represented the average-weighted value of partial similarity as overall similarity. First of all, each integral is divided into several parts, respectively.
Then, combination and matching of each part of two integrals will be conducted. Finally, the degree of similarity of each matched pair is calculated to produce an average-weighted value that represented the overall similarity. The method was applied to the semantic expressions of concepts repeatedly, in order to decompose the overall similarity between two semantic expressions into similarity combinations borne by the sememe pairs. The similarity between two sememes can be calculated by measuring and converting the semantic distance based on the hyponymy between the two.

4.2.2 Reasoning Rules Generation Based on Similarity Calculation

In order to improve the accuracy of directional evolution rules, this section proposes different similarity calculation methods for different reasoning rules, as shown in the Table 6.

The Emergency-Evolution Rules are mainly determined by the element F of the event. For event classes E_a and E_b, the relationship between events can be defined according to the similarity degree of elements F. For the River-Pollution, the elements F can be described as: F_human (Illegal discharge of sewage), F_natural (Discharge of toxic substance exceeds water self-purification capacity), F_society (Defects in sewage treatment mechanisms); And the element F of Poisoning by residents in drainage basin can be expressed as: F_human (Drink polluted water), F_natural (River pollution in the surrounding area), F_society (Defects in water treatment mechanism).

We define the F-similarity formula as follows:

\[ Sim(F_a, F_b) = \sum_{i=1}^{3} (\omega_{syn} S_{syn}(F_a, F_b) + \omega_{sem} S_{sem}(F_a, F_b)) \]

Among them, the syntax similarity of F_a and F_b is expressed as \( S_{syn}(F_a, F_b) \), while the semantic similarity as \( S_{sem}(F_a, F_b) \). \( F_i \in \{ F_{human}, F_{natural}, F_{society} \} \), the weight values of syntax similarity and semantic similarity is expressed as \( \omega_{syn} \), \( \omega_{sem} \), and different values are allocated according to the different event classes. For the emergency event discussed in this paper, \( \omega \) is set based on \( F_{human}(0.15, 0.3) \), \( F_{natural}(0.05, 0.15) \), \( F_{society}(0.15, 0.2) \). The two event classes with the similarity of Q could be merged, while the event classes with similarity of 2Q/3 or more could be evolved to describe the evolution rule. Merge the event classes with F-similarity is Q, associate the event classes with similarity of more than 2Q/3 and describe the reasoning rules.

The Emergency-Solution Rules can be considered based on the element A, O, T, P of the emergency event. The similarity calculation related to these rules as follow:

\[ Sim(E_a, E_b) = \sum_{i=1}^{4} (\omega_{syn} S_{syn}(E_a, E_b) + \omega_{sem} S_{sem}(E_a, E_b)) \]

The influence degree of different event elements has differences. This section assigns different weights to each event element. If there is no same element in the certain events, the similarity of events is denoted by 0 while the similarity is 1 when two events are exactly the same. For example, in the River-Pollution event, the element O is sewage/river, the element P is polluted drainage area and the element A is sewage discharge while in the EPA investigation event, the EPA investigate sewage as element O and monitor polluted drainage area as the element P. The coincidence of elements between two events can be used to calculate the similarity in order to correlate different events. However, event elements have a great difference in the ability to represent the event knowledge, so the different weight should be assigned to the certain element, as follows: \( \omega_A = 0.35 \), \( \omega_O = 0.3 \), \( \omega_T = 0.15 \), \( \omega_P = 0.2 \).

The Emergency-Resource Utilization Rules can be evaluated according to the event element R. For two event classes E_a and E_b, the relativity among events can be related to the similarity of element R. The similarity calculation is similar to the element F. Like in the event River-Pollution, the element R can be expressed as \( R_{human} \) (EPA), \( R_{material} \) (water quality, sewage treatment mechanisms), \( R_{society} \) (media reports). The element R of the event Biological community change caused by river pollution can be represented as \( R_{human} \) (EPA). \( R_{material} \) (water quality, sewage treatment mechanisms, medical equipment), \( R_{society} \) (media reports, public opinion).

We define the calculation formula of element R similarity as follow:

\[ Sim(R_a, R_b) = \sum_{i=1}^{3} (\omega_{syn} S_{syn}(R_a, R_b) + \omega_{sem} S_{sem}(R_a, R_b)) \]

Among them, \( S_{syn} \) \( R_a \) and \( R_b \) is used to represents the syntax similarity of \( R_a \) and \( R_b \). \( S_{sem} \) \( R_a \) and \( R_b \) represents the semantic similarity of \( R_a \) and \( R_b \). \( \omega_{syn} \), \( \omega_{sem} \) mean the weight of syntax similarity and semantic similarity. This section sets the \( \omega \) as \( R_{human}(0.1, 0.15) \), \( R_{material}(0.2, 0.35) \), \( R_{society}(0.05, 0.15) \).

4.3 Description of Reasoning Rules

According to the method of reasoning rules generation given in the Sect. 4.2, the rules knowledge can be abstracted
from the specific case and be represented in formalized description.

Emergency-Evolution could be caused by the change of a certain event attribute. e.g. in the Discharge of Sewage event, the discharge of toxic substance exceeds the water self-purification capacity, means the change of the discharge, which evolved into the River Pollution event; And in the shooting event, casualties number over a certain value is evolved into a terrorist attack event. This kind of emergency evolution can be defined as the ‘General Element-Evolution’, like rule1, which describe general element evolution; The reasoning rules of this paper focusing on the evolution of factor element, such as River Pollution event and Poisoning by Residents in Drainage Basin event described in Sect. 4.3, define the reasoning rules for event classes with the high similarity of element F, through calculating the factor similarity. The formalized description is shown in rule 2.

**Rule1.** For Discharge of sewage event, if the discharge of toxic substance exceeds the water self-purification capacity, that result in the river pollution event.

[Rule1: (?X rdf: type case: Discharge of Sewage event), (?X case: Discharge of Sewage event - discharge of toxic substance?Y), greaterThan(?Y, water self-purification capacity) → (?X rdf: type case: River Pollution event)].

**Rule2.** For River pollution event and Poisoning by Residents in Drainage Basin event, if the similarity between two event elements F is greater than 2/3Q, that can be indicated in a derivative reasoning rules.

[Rule2: (?X rdf: type case: River Pollution event), (?X case: element F of River Pollution event?Y), beSimilarTo (?Y, element F of Poisoning by Residents in Drainage Basin event) → (?X rdf: type case: Poisoning by Residents in Drainage Basin)].

Emergency-Processing Rules can be divided into prevention rules and response processing rules. The generation of rules may be deduced from the coincidence of a certain attribute in the event class. This can be described as the ‘General Emergency-Processing’, like Rule 3, and may also be reasoned by the coincidence of multiple attribute similarities. Such as the River Pollution event and EPA investigation event both have the O- sewage, P- polluted drainage area and A-sewage discharge, the emergency-processing reasoning rules as shown in rule 4. If there exist the high similarity of the element O, A, P, T, that can be associated to the prevention rules.

**Rule3.** According to the pollutants, the element O of complaints from resident event, reasoning out the EPA investigation event.


For river pollution event element.?Y) beSimilarTo (?Y, EPA Investigation event element) → (?X rdf: type case: EPA Investigation event)].

The rules of Emergency-Resource Utilization can be inferred from the similarity of recurrence element R in different event classes. Associate event classes with high similarity and the description of reasoning rules as shown in Rule 5. The resource-utilization rules can also be deduced from the change of element R in a certain event class. For example, in the river pollution event, the element R drinking water was polluted, which lead to the shortage of drinking water event, further causing the nearby supermarket panic buying drinking water event. The reasoning is described as rule 6.

**Rule5.** For River pollution event and Biological community change event, if the similarity between two event element R is greater than 2/3Q, that can be dedicate in the resource-utilization rule as follows:

[Rule5: (?X rdf: type case: River Pollution event), (?X case: River Pollution event element R?Y), beSimilarTo (?Y, Biological Community Change event element R) → (?X rdf: type case: Biological Community Change event)].

**Rule6.** For Water pollution event caused by Vehicle chemical leakage event, giving the reasoning of Nearby supermarket panic buying drinking water as the resource utilization reasoning rules, that is:

[Rule6: (?X rdf: type case: Water Pollution event), (?X case: Water Pollution event element R?Y), leadTo (?Y, shortage of drinking water) → (?X rdf: type case: Nearby Supermarket Panic Buying Drinking Water event)].

4.4 Verification of Reasoning Rules

This section builds a specific ontology pattern for an Illegal-emission event of environmental pollution through the analysis of a news case to verify the emergency ontology pattern described above.

The Xinhua News Agency has learned that in the morning of June 16, 2017, an illegal-emission event of environmental pollution was reported at Wuji, a county of Shijiazhuang city in Hebei Province. The five suspects were poisoned to death when they discharging industrial waste into a river in Wuji. Local police investigated the source of waste rapidly and arrest the suspects. Up to now, of the 12 suspects involved, 5 were killed, and the remaining 7 were all arrested.

Qiu Qifeng, the management secretary of Environmental Protection Agency said the EPA officials organized and urged the local government to take the measures of emergency management and investigation. At present, the pollution has been controlled. In the next steps, The EPA will promote the prevention laws revision of solid waste pollution, exposure the illegal enterprise and intensify the law enforcement to crack down on hazardous waste crimes.

In this case, the event Illegal-emission can be expressed as Table 7.

The event Poisoning and death can be represented as
Table 7 Description of illegal-emission event

<table>
<thead>
<tr>
<th>Event Name: Illegal-emission</th>
<th>T → Morning of June 16th</th>
<th>P → Wujia County of Shijiazhuang City in Hebei Province</th>
<th>O → The 12 suspects, the river in Wujia, industrial waste</th>
<th>A → Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rnonce</td>
<td>Discharging of industrial waste</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rgiven</td>
<td>Local police, the EIM, the management secretary of EPA</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8 Description of poisoning and death event

<table>
<thead>
<tr>
<th>Event Name: Poisoning and death</th>
<th>T → Morning of June 16th</th>
<th>P → Wujia County of Shijiazhuang City in Hebei Province</th>
<th>O → The 5 suspects</th>
<th>A → Poisoning and death</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rnonce</td>
<td>Discharge of industrial waste</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rgiven</td>
<td>The local police</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The event element similarity between Illegal-emission and Poisoning and death event is as follows:

**Rule1.** The event element similarity between Illegal-emission event and Poisoning and death event is greater than 2/3Q, the reasoning rules can be described as follows:

[Rule1: (? X rdf: type case: Illegal-emission event), (? X case: Illegal-emission event element-? Y), beSimilarTo (?Y, Poisoning and death event element) → (? X rdf: type case: Poisoning and death event)].

The Emergency-Processing Rules in this case can partially reuse the rules of generic River-Pollution Ontology Pattern described above. Such as the reuse of the Rule 4, the processing measures of EPA inferenced from the Illegal-emission event are match with the real handling measures taken in this case, which is reported as the EPA officials organized and urged the local government to take the measures of emergency management and investigation. The new reasoning rules by reusing the generic emergency ontology pattern can be represented as follows:

**Rule2.** Illegal-emission is investigated by EPA, handled by the local government. The reasoning rules is described as follows:

[Rule2: (? X rdf: type case: Illegal-emission event), (? X case: Illegal-emission event element-? Y), beSimilarTo (?Y, EPA investigation event element, local government handling event) → (? X rdf: type case: EPA investigation event, local government handling event)].

The event element similarity calculation result of Poisoning and death event and local police investigate pollutants and arrest suspects event is greater than 2/3Q, thus can generate a new reasoning rules:

**Rule3.** Illegal-emission + Poisoning and death → Local police investigate pollutants and arrest suspects, can be described as:

[Rule3: (? X rdf: type case: Poisoning and death event), (? X case: Poisoning and death event element-? Y), beSimilarTo (? Y, Local police investigate pollutants and arrest suspects event element) → (? X rdf: type case: Local police investigate pollutants and arrest suspects event)].

Similarly, the Emergency-Prevention Rules in this case can be described as follows:

**Rule4.** The mechanism of Illegal-emission → EPA promote the prevention laws revision of solid waste pollution, expose the illegal enterprise and intensify the law enforcement to crack down on hazardous waste crimes;

Based on the reasoning of the Emergency-Resource Utilization in the ontology pattern, the reasoning rules for resource used in this case as follows:

**Rule5.** Illegal-emission + Preventive measures → prevention laws revision of solid waste pollution, illegal enterprises, law enforcement;

**Rule6.** Illegal-emission + Preventive measures → police resources, EPA resources, public opinions;

5. Conclusion and Future Work

This paper puts forward a generic Emergency Ontology Pattern to describe emergencies occurrence and response. The occurrence module provides a complete description of emergency trigger, evolution and closure, while the corresponding solutions in response module describe the prevention, processing and rehabilitation of emergency. To realize the reasoning of emergency solutions, we utilize a hybrid reasoning method which consisted of Pellet inference machine and Jena2 inference machine with ERKB. And the event element similarity calculation method is proposed to generate reasoning rules for Emergency-Evolution, Emergency-Solution and Emergency-Resource Utilization.

Thus, the emergency system can reuse the ontology pattern to quickly construct a specific event ontology, including the evolution events evolved from the trigger event and the corresponding response measures, based on which, a reasonable prevention plan will be formulated and provided to achieve ontology expansion, as well as to realize the emergency processing reasoning, helping decision makers respond efficiently.

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References

Types of Ontology Design Pattern: http://ontologydesignpatterns.ode.org

Examples of Ontology Design Pattern:
- D2.5.2 Pattern based ontology design: methodology and software support,” NeOn project, 2010.
- Types of Ontology Design Pattern: http://ontologydesignpatterns.ode.org/ODPA.

Yue Tan was born in 1992. She is a master candidate at Shanghai University. Her research interests include knowledge representation and reasoning, etc.

Wei Liu was born in 1978. He received the Ph.D. degree from Shanghai University in 2005. Now he is an associate professor at Shanghai University. His research interests include knowledge representation and reasoning, semantic network and ontology technologies, etc.

Zhenyu Yang was born in 1994. He is a master candidate at Shanghai University. His research interests include description logic, knowledge reasoning, etc.
Xiaoni Du was born in 1972. She received M.S degree from LanZhou University in 2000 and Ph.D degree in Cryptography from Xidian University in 2008. She has been a professor in Northwest Normal University. Her research interests include cryptography, coding theory and information security.

Zongtian Liu was born in 1946. He received the M.S. degree from Beijing University of Aeronautics and Astronautics in 1982. Now he is a professor and Ph.D. supervisor at Shanghai University. His research interests include artificial intelligence and software engineering, etc.