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Development of a method for ontology-based empirical knowledge representation and reasoning

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ABSTRACT

In the knowledge economy era of the 21st century [14,17], the competitive advantage of enterprises has shifted from visible equipment, capital and labor in the past to invisible knowledge nowadays. Knowledge can be distinguished into tacit knowledge and explicit knowledge. Meanwhile, tacit knowledge largely encompasses empirical knowledge difficult to be documented and generally hidden inside of personal mental models. The inability to transfer tacit knowledge to organizational knowledge would cause it to disappear after knowledge workers leaving their post, ultimately losing important intellectual assets for enterprises. Therefore, enterprises attempting to create higher knowledge value are highly concerned with how to transfer personal empirical knowledge inside of an enterprise into an organizational explicit knowledge by using a systematic method to manage and share such valuable empirical knowledge effectively.

This study develops a method of ontology-based empirical knowledge representation and reasoning, which adopts OWL (Web Ontology Language) to represent empirical knowledge in a structural way in order to help knowledge requesters clearly understand empirical knowledge. An ontology reasoning method is subsequently adopted to deduce empirical knowledge in order to share and reuse relevant empirical knowledge effectively. Specifically, this study involves the following tasks: (i) analyze characteristics for empirical knowledge, (ii) design an ontology-based multi-layer empirical knowledge representation model, (iii) design an ontology-based empirical knowledge concept schema, (iv) establish an OWL-based empirical knowledge ontology, (v) design reasoning rules for ontology-based empirical knowledge, (vi) develop a reasoning algorithm for ontology-based empirical knowledge, and (vii) implement an ontology-based empirical knowledge reasoning mechanism.

Results of this study facilitate the tacit knowledge storage, management and sharing to provide knowledge requesters with accurate and comprehensive empirical knowledge for problem solving and decision support.

1. Introduction

The global economy has shifted recently from a manufacturing-based value system to a knowledge-based one. Knowledge is essential for entrepreneurial success in the knowledge economy era. Capable of deciding the life or death of an enterprise, knowledge application has become pivotal for enhancing entrepreneurial competitiveness. Consequently, an effective means of improving the competitive advantage of an enterprise is to promote its organizational knowledge value through knowledge accumulation and sharing, as well as effective management of the accumulated empirical knowledge from employees in an enterprise. The increasing importance of an enterprise to implement knowledge management [4,9,13] in the knowledge economy era is thus apparent.

Enterprise knowledge management can be implemented as either a systematization strategy or a personalization strategy [13,26]. Systematization strategy largely focuses on managing explicit knowledge and increasing the dispersion and distribution of explicit knowledge through information systems. Meanwhile, personalization strategy allows experts to own tacit knowledge by cooperating and communicating with a certain expert. Additionally, tacit knowledge [7,12] generally symbolizes an enterprise value and is generally hidden inside of personal mental models. The inability to transfer tacit knowledge to organizational knowledge (i.e., explicit knowledge) would cause it to disappear after knowledge workers leave their post, ultimately losing important intellectual assets for enterprises. Therefore, enterprise attempting to create higher knowledge value are highly concerned with how to transfer personal empirical knowledge inside of an enterprise into organizational explicit knowledge by using a knowledge-based system to manage and share such valuable empirical knowledge effectively.

Recent studies [2,17,30,32,34,36,37] indicated that most knowledge-based systems cannot effectively address the representation, storage and reasoning for empirical knowledge to offer accurate and comprehensive empirical knowledge for knowledge requesters. This circumstance incurs a bottleneck when sharing personal empirical knowledge in an enterprise.

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Ontology [5,8,10,11,19,24] refers to a consensus that defines an entity, attribute and relationship among knowledge concepts within a specific domain using explicit descriptions and specifications that present an interoperable format understandable by both humans and machines, thereby it can be used for building knowledge-based systems.

This study develops a method of ontology-based empirical knowledge representation and reasoning, which mainly uses OWL (Web Ontology Language) to represent empirical knowledge in a structural manner to help knowledge requesters clearly understand the empirical knowledge. An ontology reasoning method is subsequently adopted to deduce empirical knowledge in order to share and reuse relevant empirical knowledge effectively. Specifically, this study involves the following tasks: (i) analyze characteristics for empirical knowledge, (ii) design an ontology-based multi-layer empirical knowledge representation model, (iii) design an ontology-based empirical knowledge concept schema, (iv) establish an OWL-based empirical knowledge ontology, (v) design reasoning rules for ontology-based empirical knowledge, (vi) develop a reasoning algorithm for ontology-based empirical knowledge, and (vii) implement an ontology-based empirical knowledge reasoning mechanism.

The rest of this paper is organized as follows. Section 2 defines the ontology-based representation model for empirical knowledge based on the identified characteristics of empirical knowledge. Section 3 then describes the ontology-based reasoning method for empirical knowledge. Next, Section 4 presents an example of financial diagnosis of an enterprise to illustrate how to implement the proposed method of ontology-based empirical knowledge representation and reasoning. Section 5 summarizes the results of implementing a prototype ontology-based empirical knowledge reasoning mechanism. Conclusions are finally drawn in Section 6, along with recommendations for future research.

2. Design of ontology-based empirical knowledge representation model

This section analyzes the characteristics of empirical knowledge and then describes the design of an empirical knowledge representation model as well as empirical knowledge concept schema by using ontology techniques.

Table 1
Empirical knowledge characterization.

	Empirical Knowledge	Description
Composition Element	Problem/Cause/ Solution	As either a problem solving method or a modified action, empirical knowledge can be described by three elements of problem, cause, and solution.
Feature	Tacit	Characterized as generally having a particular context and personalization, empirical knowledge is not easily understood, learned, imitated, communicated, transferred, and shared.
Characteristic	Hierarchical	Empirical knowledge can be distinguished into different layers based on the use purpose.
	Descriptive	"Descriptive" refers to the concept, class, and structure of empirical knowledge.
	Causal	"Causal" refers to the causality and consequence of empirical knowledge.
	Procedural	"Procedural" refers to the operational activity and procedure of an event.
	Relational	"Relational" refers to how operational activities of an event are related.
Trait	Action-oriented	Empirical knowledge can be viewed as action-oriented knowledge, which is represented by conditional action.
	Skillful	Skill indicates the objective-oriented expressional behavior, which is difficult to be represented by language. While empirical knowledge can be treated as action-oriented knowledge, an action can represent knowledge through its skill.

2.1. Empirical knowledge characterization

Based on reviewing and integrating relevant empirical knowledge literature [1,3,16,18,22,23,25–29,31,33,36,39], empirical knowledge is used here to mean: difficult and costly to transfer, making it considerably less mobile than more explicit forms. Firms can possess unique capabilities that are hard to replicate and often are invisible to outside observers. For a notable example is particular knowledge such as empirical rule or know-how.

This study analyzes and explains empirical knowledge in terms of composition element, trait, characteristic, and feature, as shown in Table 1.

2.2. Ontology-based empirical knowledge representation model design

This section first divides empirical knowledge into four different layers of "know-what", "know-why", "know-how", and "know-with" based on the empirical knowledge characterization in Section 2.1. The conceptual model of ontology-based multi-layer empirical knowledge representation is then designed by using ontology techniques, as shown in Fig. 1.

In Fig. 1, descriptive empirical knowledge is defined as a know-what layer that identifies class, hierarchy, layer, and composition of empirical knowledge; in addition, the relationships include the

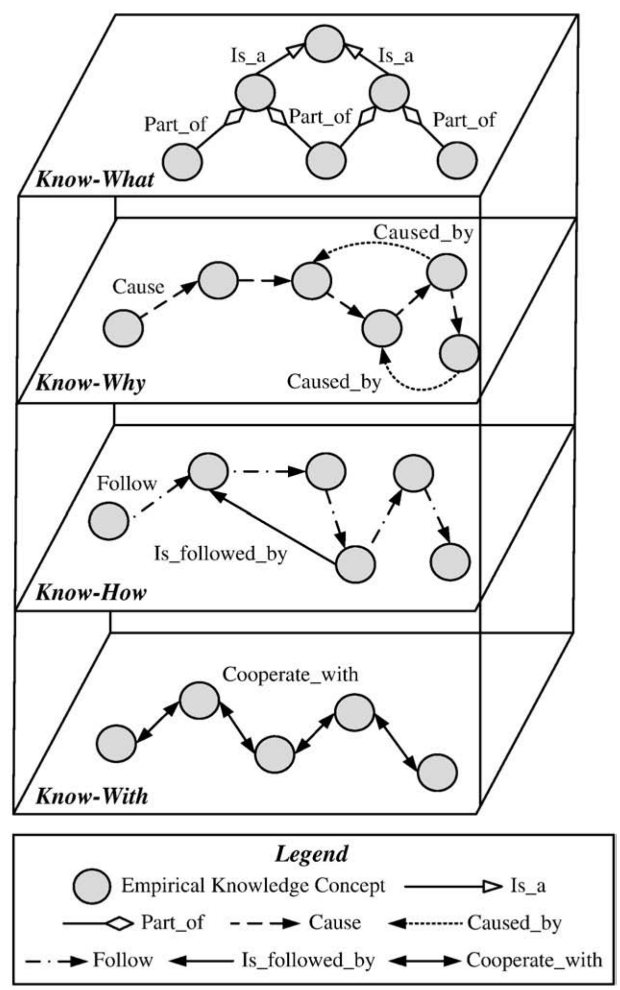

Fig. 1. Conceptual model of ontology-based multi-layer empirical knowledge representation.

taxonomy relationship “Is_a” and the partonomy relationship “Part_of”. Casual empirical knowledge is treated as a know-why layer that explains the causality and is a consequence of empirical knowledge. Therefore, the relationships are defined as “Cause” and “Caused_by”, respectively. Moreover, procedural empirical knowledge is defined to a know-how layer that describes the operational activity and procedure of an event; the relationships are “Follow” and “Is_followed_by”. Finally, the know-with layer mainly presents the relational empirical knowledge that records the relationships among operational activities of an event. The relationship is therefore defined as “Cooperate_with” to represent the collaboration among empirical knowledge concepts.

2.3. Ontology-based empirical knowledge concept schema design

For the empirical knowledge concept in the conceptual model of ontology-based empirical knowledge representation designed in Section 2.2, this section adopts the object-oriented method [20,38] to design an concept schema of empirical knowledge, as shown in Fig. 2. The schema is used to construct empirical knowledge ontology, so as to design reasoning rules and reason empirical knowledge. The empirical knowledge concept schema consists of three elements of concept, property, and relationship. Each element is described as follows:

· *Concept*: Concept refers to the name of the basic unit that can constitute an empirical knowledge ontology to express a visible or invisible object.
· *Property*: Empirical knowledge properties include “Concept_ID”, “Definition”, “Synonym”, “Appearance Reason”, “Status”, and “Action”. Meanwhile, “Concept_ID” refers to the number of empirical knowledge concepts, while the property “Definition” describes a certain concept of empirical knowledge, making it easy to understand and specify. Furthermore, the property “Synonym” describes the same semantic using various terms for an empirical knowledge concept. Additionally, “Appearance Reason” and “Status” are defined based on the causal relationships “Cause” and “Cause_by” for expressing casual empirical knowledge (know-why layer). For the rationality of logical reasoning, the value of property “Appearance Reason” is defined to have one or more characteristic values according to particular domain requirements in order to properly express the appearance reason of an empirical knowledge concept, while the value of property “Status” is either normal or abnormal. The property “Action” is adopted for expressing the procedural empirical knowledge (know-how layer) or relational empirical knowledge (know-with layer) based on the procedural relationships “Follow” and “Is_followed_by” or the cooperative relationship “Cooperate_with”. The value of property “action” refers to a characteristic value based on the particular domain requirements in order to satisfy the rationality of logical reasoning.
· *Relationship*: Relationships between empirical knowledge concepts include “Is_a”, “Part_of”, “Cause”, “Cause_by”, “Follow”, “Is_followed_by”, and “Cooperate_with”. Meanwhile, the relationship “Is_a” indicates the classification relationship between empirical knowledge concepts, while the relationship “Part_of” indicates the part-whole relationship between empirical knowledge concepts. Moreover, the relationships “Cause” and “Cause_by” represent the causal relationship between empirical knowledge concepts. Finally, the relationships “Follow” and “Is_followed_by” refer to the procedural relationship between empirical knowledge concepts. Meanwhile, the relationship “cooperate_with” is the collaborative relationship between empirical knowledge concepts.

3. Development of ontology-based empirical knowledge reasoning method

Based on the designed ontology-based empirical knowledge representation model in Section 2, this section develops related techniques to empirical knowledge reasoning, which involves “OWL-based empirical knowledge ontology establishment”, “ontology-based reasoning rules design for single-layer empirical knowledge”, “ontology-based reasoning rules design for cross-layer empirical knowledge”, and “reasoning algorithm design for ontology-based empirical knowledge” as well.

3.1. Establishment of OWL-based empirical knowledge ontology

According to the conceptual model of ontology-based empirical knowledge representation and the ontology-based empirical knowledge concept schema designed in Section 2, an OWL-based empirical knowledge ontology is developed in the following based on the basic axiom and constraint of OWL DL [6,15,21] and OWL language, thus paving the way for reasoning rules design of ontology-based empirical knowledge. Table 2 lists the relevant symbols for establishing OWL-based empirical knowledge ontology.

In Table 2, OWL-based empirical knowledge ontology is composed of different OWL constructs. Each OWL construct can be represented by a different DL Syntax. Each OWL construct is detailed as bellow.

(i) *rdf:subClassof*: the hierarchical relationship between two concept classes.
(ii) *owl:ObjectProperty*: the object relationship between two concept objects.
(iii) *owl:TransitiveProperty*: the inheritance relationship between two concepts. In the relationship, the inheritance inherits the characteristics from the original concept that had been inherited.

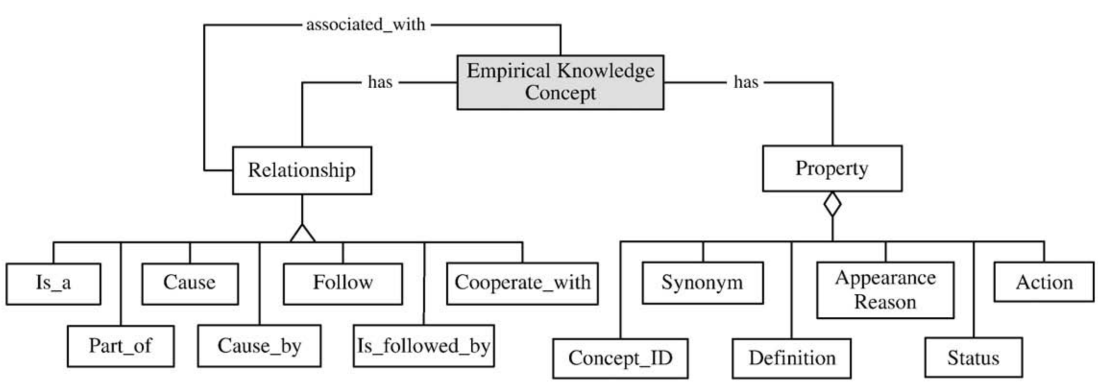

Fig. 2. Empirical knowledge concept schema.

Table 2
Relevant symbols for establishment of OWL-based empirical knowledge ontology.

OWL construct	DL syntax	Relationship of empirical knowledge ontology
rdf:subClassof	$\subseteq$	Is_a
owl:ObjectProperty	$P \subseteq P_i$	Part_of, Cause, Follow, Cooperate_with
owl:TransitiveProperty	$P^+ \subseteq P$	
owl:SymmetricProperty	$P_1 \equiv P_1^-$	Cooperate_with
owl:inverseOf	$P \equiv P^-$	Has_part, Caused_by, Is_followed_by, …etc.
OWL Construct	DL Syntax	Property of Empirical Knowledge Ontology
owl:DatatypeProperty	$U \subseteq U_i$	Appearance Reason, Status, Action
owl:minCardinality	$\geq$n P	Appearance Reason
owl:maxCardinality	$\leq$n P	Status, Action

(iv) *owl:SymmetricProperty*: the relationship symmetry between two concepts.
(v) *owl:inverseOf*: the reversibility between concept relationships.
(vi) *owl:DatatypeProperty*: the data property of a concept.
(vii) *owl:minCardinality*: constraint on the minimum of a property value.
(viii) *owl:maxCardinality*: constraint on the maximum of a property value.

By using the above OWL constructs, the empirical knowledge concept, relationship and property of OWL-based empirical knowledge ontology are established, as shown in Figs. 3 and 4, respectively.

Fig. 3 shows the empirical knowledge concept and relationship of OWL-based empirical knowledge ontology. First, the empirical knowledge ontology uses the OWL construct *rdf:subClassof* to represent a situation in which the taxonomy relationship "Is_a"exists between the empirical knowledge concepts A and B, implying that the empirical knowledge concept A is the subclass of empirical knowledge concept B. The partonomy relationship "Part_of" exists between empirical knowledge concepts D and E, indicating that empirical knowledge concept D belongs to empirical knowledge concept E. Additionally, the partonomy relationship "Part_of" can become the transitive relationship through the OWL construct *owl:Transitive-Property*. Moreover, a causal relationship "Cause" exists between empirical knowledge concepts H and I. Therefore, the relationship "Caused_by" is the inversive relationship of the relationship "Cause" by using the OWL construct *owl:inverseOf*. A cooperative relationship "Cooperate_with" exists between the empirical knowledge concepts N and O, implying that empirical knowledge concept N cooperates with empirical knowledge concept O. Through the OWL construct *owl: SymmetricProperty*, the cooperative relationship "Cooperate_with" can be the symmetric relationship.

Fig. 4 illustrates the property of OWL-based empirical knowledge ontology. The empirical knowledge concept possesses properties "Appearance Reason" and "Status"; they are both defined as the OWL construct *owl:DatatypeProperty*. For the rationality of logical reasoning, the minimum value of property "Appearance Reason" is limited to be 1 (by *owl:minCardinality*), suggesting that filling in one or more property values to describe appearance reason is necessary. Additionally, the maximum value of property "Status" is identified as 1 (by *owl:maxCardinality*) to fill in the value "Normal" or "Abnormal".

3.2. Ontology-based reasoning rules design for single-layer empirical knowledge

According to Ronald et al. (2000) [31], the knowledge representation method and the logical rules used for reasoning must be considered in designing reasoning rules. Meanwhile, description logics can be applied to related reasoning methods and can effectively support the ontology language OWL DL as well as identify implied knowledge through ontology reasoning methods to facilitate the sharing of tacit knowledge [8,19,24,35]. Therefore, this section describes the ontology-based reasoning rules for single-layer empirical knowledge based on the OWL-based empirical knowledge ontology and related methods of knowledge reasoning, description logics, OWL DL basic axiom and constraint [6,15,21] established from

```
<owl:Class rdf:ID="Empirical_Knowledge_Concept_A">
  <rdfs:subClassOf>
    <owl:Class rdf:ID="Empirical_Knowledge_Concept_B"/>
  </rdfs:subClassOf>
</owl:Class>
<owl:TransitiveProperty rdf:ID="Part_of">
  <rdfs:domain rdf:resource="#Empirical_Knowledge_Concept_D"/>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  <rdfs:range rdf:resource="#Empirical_Knowledge_Concept_E"/>
</owl:TransitiveProperty>
<owl:TransitiveProperty rdf:about="#Cause">
  <rdfs:domain rdf:resource="#Empirical_Knowledge_Concept_H"/>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
  <owl:inverseOf rdf:resource="#Caused_by"/>
  <rdfs:range rdf:resource="#Empirical_Knowledge_Concept_I"/>
</owl:TransitiveProperty>
<owl:SymmetricProperty rdf:ID="Cooperate_with">
  <rdfs:domain rdf:resource="#Empirical_Knowledge_Concept_N"/>
  <rdfs:range rdf:resource="#Empirical_Knowledge_Concept_O"/>
  <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#ObjectProperty"/>
</owl:SymmetricProperty>
```

Fig. 3. Part of OWL-based empirical knowledge ontology (empirical knowledge concept and relationship).

```
<owl:Class rdf:ID="Empirical_Knowledge_Concept">
   <rdfs:subClassOf>
     <owl:Restriction>
    <owl:maxCardinality rdf:datatype="http://www.w3.org/2001/XMLSchema#int"
        >1</owl:maxCardinality>
        <owl:onProperty>
          <owl:DatatypeProperty rdf:ID="Status"/>
        </owl:onProperty>
     </owl:Restriction>
   </rdfs:subClassOf>
   <rdfs:subClassOf>
     <owl:Restriction>
        <owl:onProperty>
          <owl:DatatypeProperty rdf:ID="AppeareanceReason"/>
        </owl:onProperty>
   <owl:minCardinality rdf:datatype="http://www.w3.org/2001/XMLSchema#int"
        >1</owl:minCardinality>
     </owl:Restriction>
   </rdfs:subClassOf>
   <rdfs:subClassOf rdf:resource="http://www.w3.org/2002/07/owl#Thing"/>
 </owl:Class>
 <owl:DatatypeProperty rdf:about="#Status">
   <rdfs:domain rdf:resource="#Empirical_Knowledge_Concept"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
   >normal,abnormal</rdfs:comment>
   <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#string"/>
 </owl:DatatypeProperty>
 <owl:DatatypeProperty rdf:about="#AppeareanceReason">
   <rdfs:domain rdf:resource="#Empirical_Knowledge_Concept"/>
   <rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#string"/>
   <rdfs:comment rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
   ></rdfs:comment>
 </owl:DatatypeProperty>
```

Fig. 4. Portion of OWL-based empirical knowledge ontology (Property).

Section 3.1, as shown in Table 3. The empirical knowledge reasoning rules in Table 3 comprise four different types of know-what, know-why, know-how, and know-with. Their descriptions are detailed as follows with Figs. 5–8 showing the conceptual models.

3.3. Empirical knowledge reasoning model in the know-what layer

Relationships in the know-what layer of empirical knowledge mainly include two types of hierarchical relationship "Is_a" and partonomy relationship "Part_of". According to Fig. 5, a hierarchical relationship "Is_a" exists between empirical knowledge concepts A and B, and also the hierarchical relationship "Is_a" between the empirical knowledge concepts B and C. Therefore, the hierarchical relationship "Is_a" tacitly exists between the empirical knowledge concepts A and C is deduced by the reasoning rule (1) from Table 3. Moreover, the relationship between empirical knowledge concepts D and E is partonomy relationship "Part_of", and the relationship between the empirical knowledge concepts E and F is also partonomy relationship "Part_of". The implied partonomy relationship "Part_of" between the empirical knowledge concepts D and E can be deduced through the reasoning rule (2) from Table 3. Additionally, an inversive relationship (Rule (3) from Table 3) exists between the partonomy relationship "Part_of" and the partial relationship "Has_part". Meanwhile, the partonomy relationship "Part_of" exists between the empirical knowledge concepts D and E, implying that the empirical knowledge concept D is a part of the empirical knowledge concept E. Thus, the fact that empirical knowledge concept E belongs to empirical knowledge concept D is identified through the reasoning rule of an inversive property (Rule (4) in Table 3).

3.4. Empirical knowledge reasoning model in the know-why layer

In the know-why layer of empirical knowledge, a causal relationship "Cause" exists between empirical knowledge concepts G and H, and a causal relationship "Cause" also exists between the empirical knowledge concepts H and I. By the reasoning rule of transitive property (Rule (5) in Table 3), the implied causal relationship "Cause" between the empirical knowledge concepts G and I is derived. Additionally, the relationship between the causal relationships "Cause" and "Caused_by" belongs to the transitive relationship (Rule (6) in Table 3), and a causal relationship "Cause" exists between the empirical knowledge concepts H and I. This finding

Table 3
Ontology-based Reasoning Rules for Single-Layer Empirical Knowledge.

Single-Layer Empirical Knowledge Type	Relationship	Reasoning rule
Know-What Layer	Is_a	(1) (?A rdfs:subClassOf ?B) ∧ (?B rdfs:subClassOf ?C) ⇒ (?A rdfs:subClassOf ?C)
	Part_of Has_part	(2) ∀D,E,F:Part-of(D,E) ∧ Part-of(E,F) ⇒ Part-of(D,F) (3) Has-part ≡ Part-of^{-1} (inverse) (4) ∀D,E:Part-of(D,E) ⇔ Has-part(E,D)
Know-Why Layer	Cause Caused_by	(5) (?Cause rdf:type owl:TransitiveProperty) ∧ (?G ? Cause ?H) ∧ (?H ? Cause ?I) ⇒ (?G ? Cause ?I) (6) Cause ≡ Caused_by^{-1} (inverse) (7) (?Cause owl:inverseOf ? Caused_by) ∧ (?H ? Cause ?I) ⇒ (?I ? Caused_by ?H)
Know-How Layer	Follow Is_followed_by	(8) (?Follow rdf:type owl:TransitiveProperty) ∧ (?J ? Follow ?K) ∧ (?K ? Follow ?L) ⇒ (?J ? Follow ?L) (9) Follow ≡ Is_followed_by^{-1} (inverse) (10) (?Follow owl:inverseOf ? Is_followed_by) ∧ (?K ? Follow ?L) ⇒ (?L ? Is_followed_by ?K)
Know-With Layer	Cooperate_with	(11) (?Cooperate_with rdf:type owl:TransitiveProperty) ∧ (?M ? Cooperate_with ?N) ∧ (?N ? Cooperate_with ?O) ⇒ (?M ? Cooperate_with ?O) (12) (?Cooperate_with rdf:type owl: SymmetricProperty) ∧ (?N ? Cooperate_with ?O) ⇒ (?O ? Cooperate_with ?N)

NOTE:
(1) Parameters A B C… denote the concept names of empirical knowledge.
(2) Symbol "^" represents the logical operator AND.
(3) Symbol "⇒"means reasoning.

suggests that empirical knowledge concept H causes the generation of empirical knowledge concept I. According to the reasoning rule of inversive property (Rule (7) in Table 3), the fact that the empirical knowledge concept I is caused by empirical knowledge concept H is deduced. Hence, their relationship is identified as "Caused_by", as shown in Fig. 6.

3.5. Empirical knowledge reasoning model in the know-how layer

Fig. 7 displays the conceptual model of empirical knowledge reasoning in the know-how layer. In the model, the procedural relationship "Follow" exists between the empirical knowledge concepts J and K, and the procedural relationship "Follow" also exists between the empirical knowledge concepts K and L. Therefore, the implied procedural relationship "Follow" between the empirical knowledge concepts J and L is identified based on the reasoning rule of the transitive property (Rule (8) in Table 3). Additionally, an inversive relationship (Rule (9) in Table 3) exists between the procedural relationships "Follow" and "Is_Followed_by" as well as a procedural relationship "Follow" exists between empirical knowledge concepts K and L, demonstrating that empirical knowledge concept L appears before empirical knowledge concept K. Through the reasoning rule of inversive property (Rule (10) in Table 3), appearance of the procedural relationship of the empirical knowledge concept K after the empirical knowledge concept L is "Is_followed_by" is derived.

3.6. Empirical knowledge reasoning model in the know-with layer

In this conceptual model of empirical knowledge in the know-with layer, a cooperative relationship "Cooperate_with" between the empirical knowledge concepts M and N and a cooperative relationship "Cooperate_with" between the empirical knowledge concepts N and O are existent. Via the reasoning rule of transitive property (Rule (11) in Table 3), the cooperative relationship "Cooperate_with" between empirical knowledge concepts M and O is therefore deduced. Additionally, a cooperative relationship "Cooperate_with" exists between empirical knowledge concepts N and O. Therefore, the fact that empirical knowledge concept O has a cooperative relationship with the empirical knowledge concept N is deduced based on the reasoning rule of synonymous relationship (Rule (12) in Table 3), as shown in Fig. 8.

3.7. Ontology-based reasoning rules design for cross-layer empirical knowledge

According to the OWL-based empirical knowledge ontology and the related methods of knowledge reasoning, description logics, and OWL DL basic axiom and constraint [14,34] established in Section 3.1, this section analyzes how the relationships among empirical knowledge in different layers are related based on the ontology-based multi-layer empirical knowledge representation model. Additionally, as well as the ontology-based reasoning rules for cross-layer empirical knowledge are designed by using ontology language OWL DL. According to Table 4, the ontology-based reasoning rules for cross-layer empirical knowledge involve three categories. They are, i.e. "know-what layer vs. know-why layer", "know-what layer vs. know-

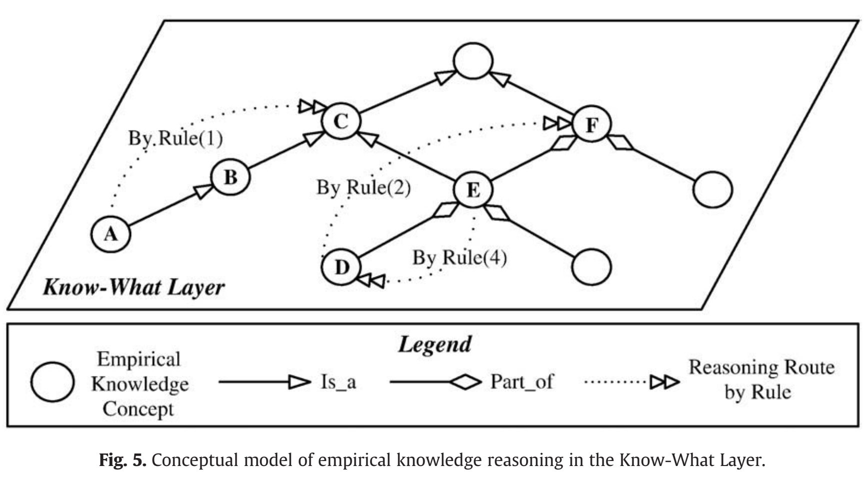

Fig. 5. Conceptual model of empirical knowledge reasoning in the Know-What Layer.

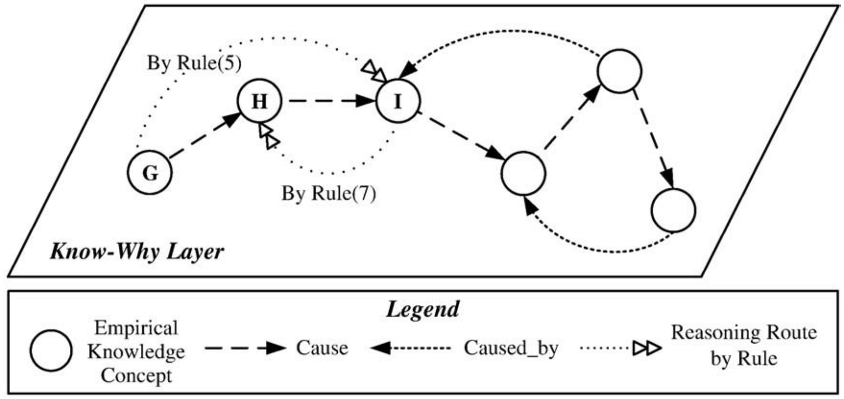

Fig. 6. Conceptual model of empirical knowledge reasoning in the Know-Why Layer.

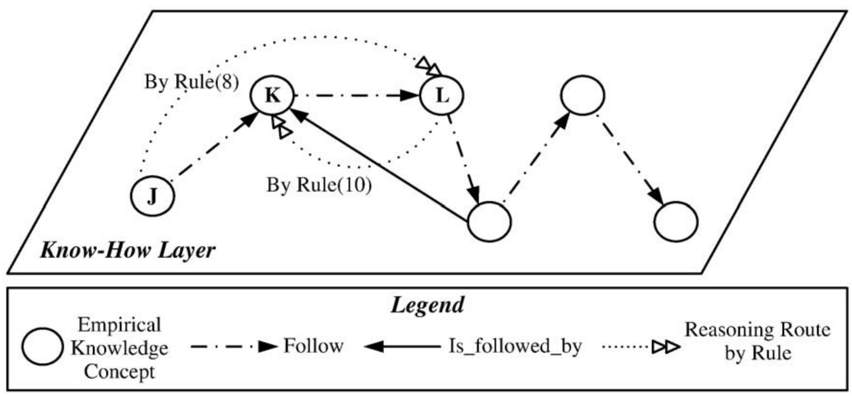

Fig. 7. Conceptual model of empirical knowledge reasoning in the Know-How Layer.

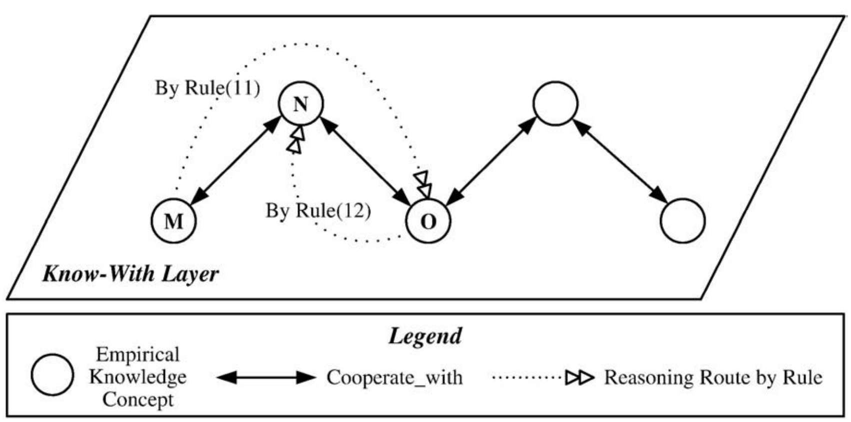

Fig. 8. Conceptual model of empirical knowledge reasoning in the Know-With Layer.

how layer", and "know-what layer vs. know-with layer", respectively. Each category is described as follows.

3.8. Empirical knowledge reasoning model between the know-what layer and know-why layer

Fig. 9 presents the conceptual model of empirical knowledge reasoning between the know-what layer and know-why layer. In the model, a causal relationship "Cause" exists between the empirical knowledge concepts X and Y and the partonomy relationship "Part_of" exists between empirical knowledge concepts Y and Z. Hence, the fact that a causal relationship "Cause" exists between the empirical knowledge concepts X and Z is derived through the reasoning rule (1) from Table 4.

3.9. Empirical knowledge reasoning model between the know-what layer and know-how layer

In the empirical knowledge reasoning between the know-what layer and know-how layer, a procedural relationship "Follow" between empirical knowledge concepts U and V and a partonomy relationship "Part_of" between empirical knowledge concepts V and

Table 4
Ontology-based reasoning rules for cross-layer empirical knowledge.

Cross-empirical knowledge type	Relationship	Reasoning rule
Know-What Layer *vs.* Know-Why Layer	Part_of Cause	(1) $X \subseteq \exists$ Cause. $Y \wedge Y \subseteq \exists$ Part-of. $Z \Rightarrow X \subseteq \exists$ Cause. Z
Know-What Layer *vs.* Know-How Layer	Part_of Follow	(2) $U \subseteq \exists$ Follow. $V \wedge V \subseteq \exists$ Part-of. $W \Rightarrow U \subseteq \exists$ Follow. W
Know-What Layer *vs.* Know-With Layer	Part_of Cooperate_with	(3) $R \subseteq \exists$ Cooperate_with. $S \wedge S \subseteq \exists$ Part-of. $T \Rightarrow R \subseteq \exists$ Cooperate_with. T

NOTE:
(1) Parameters X Y Z…denote the concept names of empirical knowledge.
(2) Symbol "^" represents the logical operator AND.
(3) Symbol "⇒" implies reasoning.
(4) Symbol "⊆" implies a subset.
(5) Symbol "∃" implies an existential quantifier.

W are existent. Consequently, the procedural relationship "Follow" between the empirical knowledge concepts U and W is found based on the reasoning rule (2) from Table 4, as shown in Fig. 10.

3.10. Empirical knowledge reasoning model between the know-what layer and know-with layer

Fig. 11 shows the conceptual model of empirical knowledge reasoning between the know-what layer and know-with layer. A cooperative relationship "Cooperate_with" exists between the empirical knowledge concepts R and S and a partonomy relationship "Part_of" exists between empirical knowledge concepts S and T, indicating that the cooperative relationship "Cooperate_with" between the empirical knowledge concepts R and T is exposed according to the reasoning rule (3) from Table 4.

3.11. Reasoning algorithm design for ontology-based empirical knowledge

This section introduces the reasoning algorithm for ontology-based empirical knowledge based on the established empirical knowledge reasoning rules in Sections 3.2 and 3.3. The ontology-based empirical knowledge reasoning algorithm involves single-layer empirical knowledge reasoning and cross-layer empirical knowledge reasoning.

3.11.1. Reasoning algorithm for single-layer empirical knowledge

According to the ontology-based reasoning rules for single-layer empirical knowledge from Section 3.2, this subsection describes the reasoning algorithm for single-layer empirical knowledge, as shown in Fig. 12. The operational steps are described in order as follows:

Step 1. Input the single-layer empirical knowledge ontology and perform the reasoning of single-layer empirical knowledge.
Step 2. Determine whether the input empirical knowledge ontology belongs to "know-what", and whether the relationship is "Is_a", "Part_of" or "Has_part". If yes, then go to Step 3 to operate the judgment of relationship value; otherwise, go to Step 4.
Step 3. If the relationship value is "Is_a", then execute the reasoning process for the relationship "Is_a". If the relationship value is "Part_of", then execute the reasoning process for the relationship "Part_of". If the relationship value is "Has_part", then execute the reasoning process for the relationship "Has_part".
Step 4. Determine whether the input empirical knowledge ontology belongs to "know-why" and whether the relationship is "Cause" or "Caused_by". If yes, then go to Step 5 to implement the judgment for relationship value; otherwise, go to Step 6.
Step 5. If relationship value is "Cause", then execute the reasoning process for the relationship "Cause". If the relationship value is "Caused_by", then execute the reasoning process for the relationship "Caused_by".

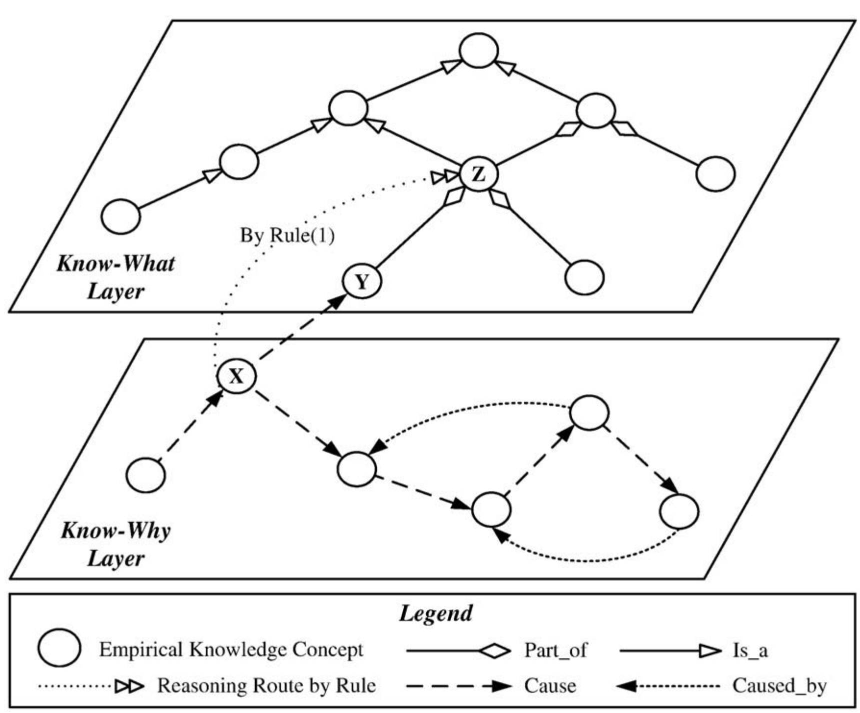

Fig. 9. Conceptual model of empirical knowledge reasoning between the Know-What Layer and Know-Why Layer.

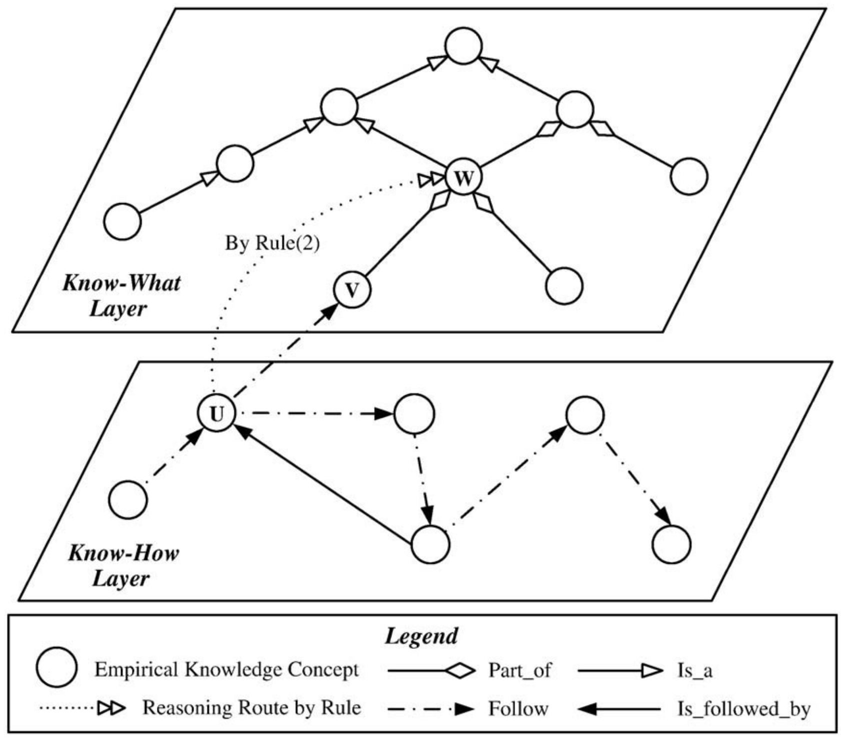

Fig. 10. Conceptual model of empirical knowledge reasoning between the Know-What Layer and Know-How Layer.

Step 6. Determine whether the input empirical knowledge ontology belongs to "know-how" and whether the relationship is "Follow" or "Is_followed_by". If yes, then go to Step 7 to proceed with the judgment for relationship value; otherwise, go to Step 8.

Step 7. If the relationship value is "Follow", then operate the reasoning process for the relationship "Follow". If the relationship value is "Is_followed_by", then operate the reasoning process for the relationship "Is_followed_by".

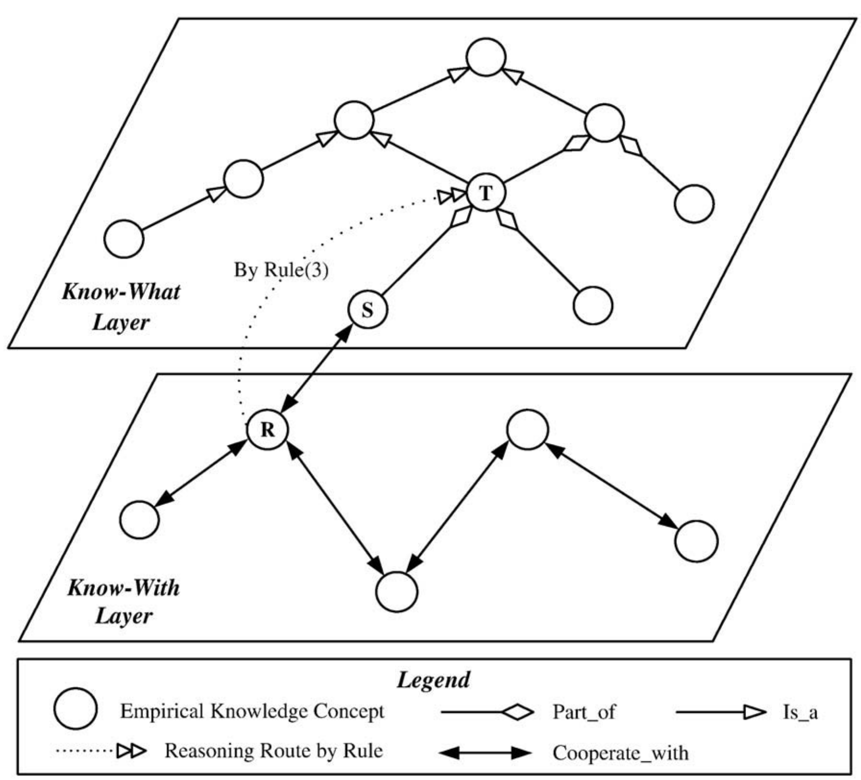

Fig. 11. Conceptual model of empirical knowledge reasoning between the Know-What Layer and Know-With Layer.

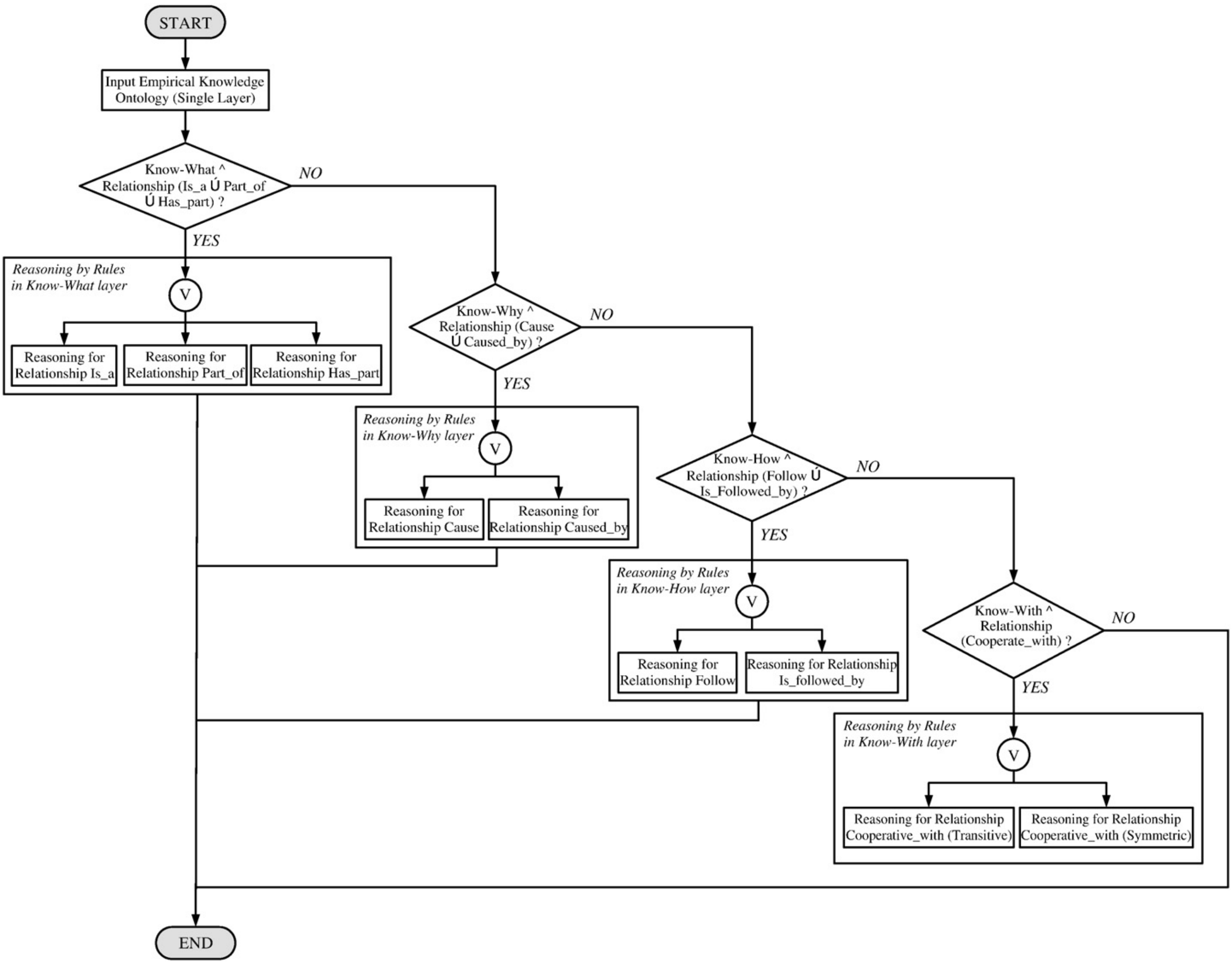

Fig. 12. Reasoning process for Single-Layer Empirical Knowledge.

Step 8. Determine whether the input empirical knowledge ontology belongs to "know-with" and whether the relationship is "Cooperate_with". If yes, then go to Step 9 to proceed with the judgment for rule value; otherwise, end the algorithm.

Step 9. If the rule value is "Transitive", then execute the reasoning process for the relationship "Transitive". If the rule value is "Symmetric", then execute the reasoning process for the relationship "Symmetric".

In Fig. 12, the reasoning process for single-layer empirical knowledge can be represented as an algorithm written in Pseudo Code (Fig. 13).

3.11.2. Reasoning algorithm for cross-layer empirical knowledge

According to results of Section 3.3, this subsection describes the reasoning algorithm for cross-layer empirical knowledge, as shown in Fig. 14. This algorithm involves the following steps:

Step 1. Input the cross-layer empirical knowledge ontology and perform the reasoning of cross-layer empirical knowledge.

Step 2. Determine whether the input empirical knowledge covers "know-what" and "know-why" and whether the relationships are "Part_of" and "Cause". If yes, then go to Step 3; otherwise, go to Step 4.

Step 3. Execute the reasoning rules for cross-layer empirical knowledge "know-what layer vs. know-why layer".

Step 4. Determine whether the input empirical knowledge covers "know-what" and "know-how" and whether the relationships are "Part_of" and "Follow". If yes, then go to Step 5; otherwise, go to Step 6.

Step 5. Execute the reasoning rules for cross-layer empirical knowledge "know-what layer vs. know-how layer".

Step 6. Determine whether the input empirical knowledge covers "know-what" and "know-with", and whether the relationships are "Part_of" and "Cooperate_with". If yes, then go to Step 7; otherwise end the algorithm process.

Step 7. Execute the reasoning rules for cross-layer empirical knowledge "know-what layer vs. know-with layer".

The reasoning process for cross-layer empirical knowledge shown in Fig. 14 can be represented as an algorithm written in Pseudo Code (Fig. 15).

4. Illustrative example of an enterprise's financial diagnosis

Based on the proposed method of ontology-based empirical knowledge representation and reasoning, the applicability and

```
Single-Layer Empirical Knowledge Reasoning Process

BEGIN
Input Empirical Knowledge Ontology (Single-Layer);
K. Layer: Knowledge Layer;
IF K. Layer is Know-What AND Relationship is Is_a OR Part_of OR Has_part
  SWITCH (Relationship)
    Case 1: Is_a
      Reasoning by Relationship Is_a;
      Break;
    Case 2: Part_of
      Reasoning by Relationship Part_of;
      Break;
    Case 3: Has_part
      Reasoning by Relationship Has_part;
      Break;
Else IF K. Layer is Know-Why AND Relationship is Cause OR Caused_by
  SWITCH (Relationship)
    Case 1: Cause
      Reasoning by Relationship Cause;
      Break;
    Case 2: Caused_by
      Reasoning by Relationship Caused_by;
      Break;
Else IF K. Layer is Know-How AND Relationship is Follow OR Is_followed_by
  SWITCH (Relationship)
    Case 1: Follow
      Reasoning by Relationship Follow;
      Break;
    Case 2: Is_followed_by
      Reasoning by Relationship Is_followed_by;
      Break;
Else IF K. Layer is Know-With AND Relationship is Cooperate_with
  SWITCH (Rule)
    Case 1: Transitive
      Reasoning by Relationship Cooperative_with (Transitive);
      Break;
    Case 2: Symmetric
      Reasoning by Relationship Cooperative_with (Symmetric);
      Break;
END
```

Fig. 13. Reasoning algorithm for Single-Layer Empirical Knowledge (Pseudo Code).

feasibility of the proposed method are demonstrated using an illustrative example of enterprise's financial diagnosis.

4.1. Ontology-based multi-layer financial diagnosis empirical knowledge

This section describes a practical example of an enterprise's financial diagnosis to establish the ontology-based multi-layer financial diagnosis empirical knowledge, as shown in Fig. 16. The knowledge representation content for each layer is discussed as below:

(1) Know-what layer: A taxonomy relationship "Is_a" exists between the empirical knowledge concepts Diet_Enterprise and Enterprise_a/Enterprise_b, implying that the empirical knowledge concepts Enterprise_a and Enterprise_b are the subclasses of the empirical knowledge concept Diet_Enterprise.

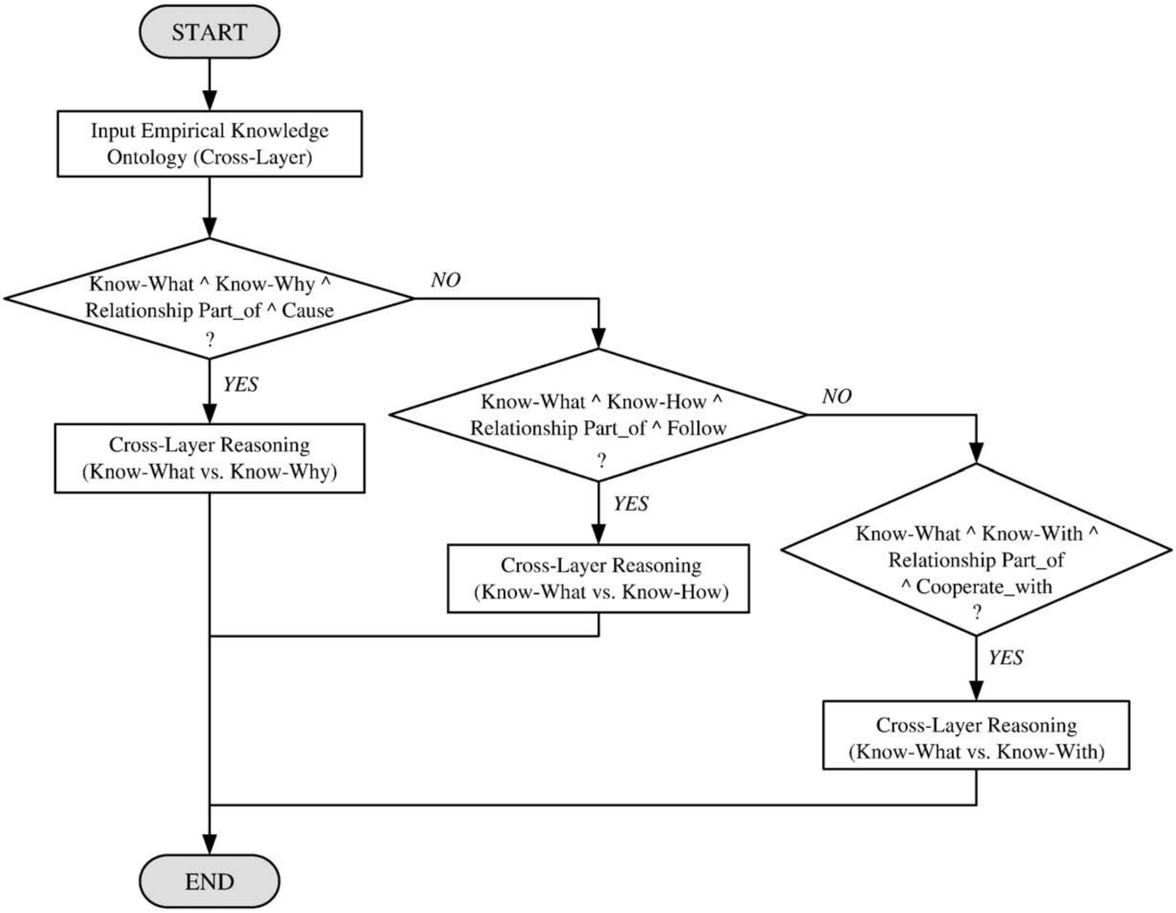

Fig. 14. Reasoning process for Cross-Layer Empirical Knowledge.

Moreover, a taxonomy relationship "Is_a" exists between the empirical knowledge concepts Company_a and Enterprise_b, indicating that empirical knowledge concept Company_a is the subclass of the empirical knowledge concept Enterprise_b. Additionally, a partonomy relationship "Part_of" exists between the empirical knowledge concepts Enterprise_a and Sub-conglomerate_1/Sub-conglomerate_2. This finding suggests that both empirical knowledge concepts Sub-conglomerate_1 and Sub-conglomerate_2 are parts of the empirical knowledge concept Enterprise_a. Meanwhile, a partonomy relationship "Part_of" exists between the empirical knowledge concepts Sub-conglomerate_2 and Subsidiary_2/Subsidiary_3/Subsidiary_4/Subsidiary_5, implying that the empirical knowledge concepts Subsidiary_2, Subsidiary_3, Subsidiary_4, and Subsidiary_5 are all parts of the empirical knowledge concept Sub-conglomerate_2.

(2) Know-why layer: A causal relationship "Cause" exists between the empirical knowledge concepts Subsidiary_3 and Subsidiary_2. Meanwhile, the empirical knowledge concept Subsidiary_3 owns two properties "AppearanceReason" and "Status". The

Cross-Layer Empirical Knowledge Reasoning Process

BEGIN

Input Empirical Knowledge Ontology (Cross-Layer);

K. Layer: Knowledge Layer;

IF K. Layers are Know-What and Know-Why **AND** Relationships are Part_of and Cause

    Cross-Layer Reasoning between Know-What and Know-Why

Else IF K. Layers are Know-What and Know-How **AND** Relationships are Part_of and Follow

    Cross-Layer Reasoning between Know-What and Know-How

Else IF K. Layer are Know-What and Know-How **AND** Relationship are Part_of and Cooperate_with

    Cross-Layer Reasoning between Know-What and Know-With

END

Fig. 15. Reasoning algorithm for Cross-Layer Empirical Knowledge (Pseudo Code).

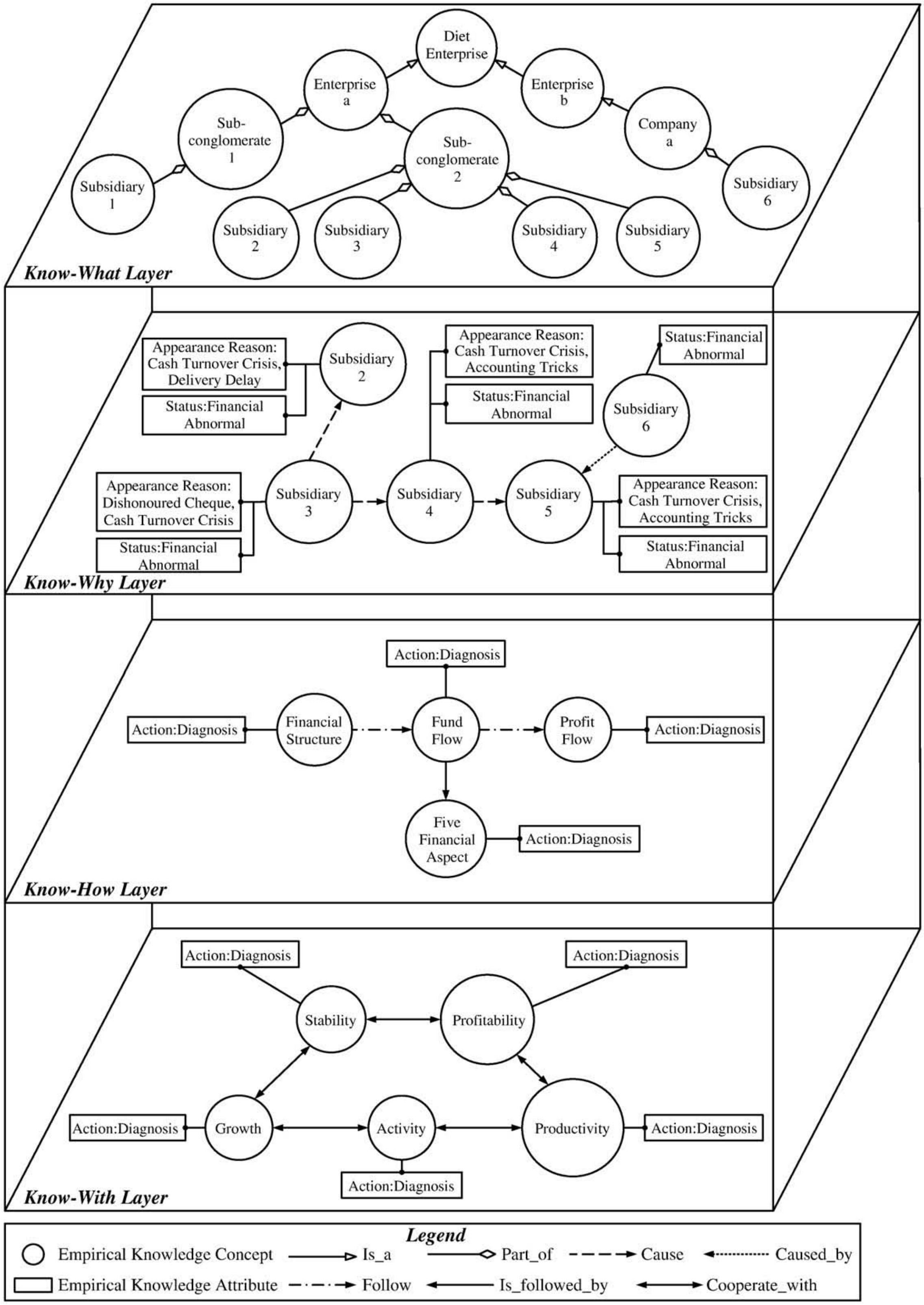

Fig. 16. Ontology-based multi-layer financial diagnosis empirical knowledge representation.

former values are dishonoured cheque and cash turnover crisis, while the latter value is financial abnormal. Concerning the empirical knowledge concept Subsidiary_2, the values of the property "AppearanceReason" are cash turnover crisis and delivery delay, while the value of the property "Status" is financial abnormal. The relationships and property values from the above statement address the fact that the financial abnormal situation occurs in Subsidiary_2, as attributed to the financial abnormal situation in Subsidiary_3. Moreover, a causal relationship "Cause" exists between the empirical knowledge concepts Subsidiary_3 and Subsidiary_4. The values of the property "AppearanceReason" from the empirical knowledge concept

Subsidiary_4 are cash turnover crisis and accounting tricks, while the value of the property “Status” is financial abnormal. These relationships and property values imply that a financial abnormal situation occurs in Subsidiary_4, as attributed to the financial abnormal situation in Subsidiary_3”. Additionally, a causal relationship “Cause” exists between the empirical knowledge concepts Subsidiary_4 and Subsidiary_5. The values of the property “AppearanceReason” from Subsidiary_5 are cash turnover crisis and accounting tricks, while the value of the property “Status” is financial abnormal. Based on these relationships and property values, a financial abnormal situation occurs in Subsidiary_5, as attributed to the financial abnormal situation in Subsidiary_4”. Finally, the relationship “Caused_by” exists between the empirical knowledge concepts Subsidiary_6 and Subsidiary_5, and the value of the property “Status” from Subsidiary_6 is financial abnormal. The relationship and the property value indicate that reason of the financial abnormal situation in Subsidiary_6 is attributed to Subsidiary_5.

(3) Know-how layer: The empirical knowledge concepts in this layer contain Profit_Flow, Fund_Flow, Financial_Structure, and Five_Financial_Aspect. Each concept has one property “Action”, and its value is diagnosis. In this case, a procedural relationship “Follow” exists between the empirical knowledge concepts, which addresses a situation in which financial diagnosis is proceeded with for an enterprise's financial abnormal problem. The diagnosis process involves three main steps: profit flow diagnosis, fund flow diagnosis, and financial structure diagnosis. While the relationship “Is_follow_by” exists between the empirical knowledge concepts Fund_Flow and Five_Financial_Aspect, this statement expresses a situation in which the fund flow diagnosis must be performed before the five_financial_aspect diagnosis in a financial diagnosis process.

(4) Know-with layer: The empirical knowledge concepts in this layer include Stability, Profitability, Growth, Activity, and Productivity. Their property values are all diagnosis. The cooperative relationship “Cooperate_with” exists between the empirical knowledge concepts, explaining that these five different diagnoses must be cooperated with each other.

4.2. OWL-based financial diagnosis empirical knowledge ontology

Based on the established ontology-based multi-layer financial diagnosis empirical knowledge, this section establishes the OWL-based financial diagnosis empirical knowledge ontology by using OWL constructs, as shown in Figs. 17 and 18. Meanwhile, Fig. 17 shows the part of the empirical knowledge concept and relationship of OWL-based financial diagnosis empirical knowledge ontology, while Fig. 18 depicts the part of property of OWL-based financial diagnosis empirical knowledge ontology.

4.3. Ontology-based single-layer financial diagnosis empirical knowledge reasoning

This section illustrates the ontology-based single-layer financial diagnosis empirical knowledge reasoning by using the empirical knowledge ontology “know-why” as an example. For this example, the empirical knowledge ontology “know-why” is first represented by using OWL DL. Subsequently, reasoning in the know-why layer of financial diagnosis empirical knowledge is performed through the defined ontology-based reasoning rules for single-layer empirical knowledge.

Table 5 lists the partial contents of the reasoning in the know-why layer of financial diagnosis empirical knowledge before and after the executing reasoning process. Meanwhile, a causal relationship “Cause” exists between the empirical knowledge concepts Subsidiary_3 and Subsidiary_4, as well as between the empirical knowledge concepts Subsidiary_4 and Subsidiary_5 (Fig. 19). Thus, the causal

```
<owl:Class rdf:ID="Empirical_Knowledge_Concept_A">
   <rdfs:subClassOf>
      <owl:Class rdf:ID="Empirical_Knowledge_Concept_B"/>
   </rdfs:subClassOf>
</owl:Class>
<Empirical_Knowledge_Concept_A rdf:ID=" Company_a"/>
<Empirical_Knowledge_Concept_B rdf:ID=" Enterprise_a "/>
<Empirical_Knowledge_Concept_D rdf:ID="Subsidiary_1">
   <Part_of>
      <Empirical_Knowledge_Concept_E rdf:ID="Sub-conglomerate_1"/>
   </Part_of>
</Empirical_Knowledge_Concept_D>
<Empirical_Knowledge_Concept_I rdf:ID="Subsidiary_5">
   <Caused_by>
      <Empirical_Knowledge_Concept_H rdf:ID="Subsidiary_4">
         <Cause rdf:resource="#Subsidiary_5"/>
      </Empirical_Knowledge_Concept_H>
   </Caused_by>
</Empirical_Knowledge_Concept_I>
<Empirical_Knowledge_Concept_N rdf:ID=" Stability">
   <Cooperate_with>
      <Empirical_Knowledge_Concept_O rdf:ID="Profitability">
         <Cooperate_with rdf:resource="# Stability "/>
      </Empirical_Knowledge_Concept_O>
   </Cooperate_with>
</Empirical_Knowledge_Concept_N>
```

Fig. 17. Portion of OWL-based financial diagnosis empirical knowledge ontology (empirical knowledge concept and relationship).

relationship “Cause” exists between the empirical knowledge concepts Subsidiary_3 and Subsidiary_5 is deduced by using the reasoning rule of transitive property (Rule (1) in Table 5). Moreover, the relationship “Cause” is the inversive relationship of the relationship “Caused_by” (Rule (2) in Table 5). Therefore, the relationship “Caused_by” between the empirical knowledge concepts Subsidiary_5 and Subsidiary_4, between the empirical knowledge concepts Subsidiary_4 and Subsidiary_3, and between the empirical knowledge concepts Subsidiary_5 and Subsidiary_3 are deduced by applying the reasoning rule of inversive property (Rule (3) in Table 5).

4.4. Ontology-based cross-layer financial diagnosis empirical knowledge reasoning

This section demonstrates the feasibility of the proposed cross-layer empirical knowledge reasoning method by selecting the cross-layer empirical knowledge ontology “know-what layer vs. know-why layer” as an illustrative example. In this example, the ontology language OWL DL is initially adopted to represent the cross-layer financial diagnosis empirical knowledge “know-what layer vs. know-why layer”. Next, the defined ontology-based reasoning rules for

```
<owl:Class rdf:ID="Empirical_Knowledge_Concept">
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:onProperty>
                <owl:DatatypeProperty rdf:ID="AppeareanceReason"/>
            </owl:onProperty>
<owl:minCardinality rdf:datatype="http://www.w3.org/2001/XMLSchema#int"
            >1</owl:minCardinality>
        </owl:Restriction>
    </rdfs:subClassOf>
    <rdfs:subClassOf>
        <owl:Restriction>
            <owl:onProperty>
                <owl:DatatypeProperty rdf:ID="Status"/>
            </owl:onProperty>
<owl:maxCardinality rdf:datatype="http://www.w3.org/2001/XMLSchema#int"
            >1</owl:maxCardinality>
        </owl:Restriction>
    </rdfs:subClassOf>
    <rdfs:subClassOf rdf:resource="http://www.w3.org/2002/07/owl#Thing"/>
</owl:Class>
<owl:DatatypeProperty rdf:about="#Status">
    <rdfs:domain rdf:resource="#Empirical_Knowledge_Concept"/>
</owl:DatatypeProperty>
<owl:DatatypeProperty rdf:about="#AppeareanceReason">
    <rdfs:domain rdf:resource="#Empirical_Knowledge_Concept"/>
</owl:DatatypeProperty>
<Empirical_Knowledge_Concept rdf:ID="Subsidiary_3">
    <status rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
    >Financial Abnormal</status>
<AppeareanceReason rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
    >Cash Turnover Crisis</AppeareanceReason>
<AppeareanceReason rdf:datatype="http://www.w3.org/2001/XMLSchema#string"
    >Dishonoured Cheque</AppeareanceReason>
</Empirical_Knowledge_Concept>
```

Fig. 18. Portion of OWL-based financial diagnosis empirical knowledge ontology (Property).

Table 5
OWL-based financial diagnosis empirical knowledge reasoning contents (Know-Why Layer).

Financial diagnosis empirical knowledge before reasoning	<owl:**TransitiveProperty** rdf:about="#Cause"> <rdfs:domain rdf:resource="#G"/> <rdf:type rdf:resource="http://www.w3.org/2002/07/ owl#ObjectProperty"/> <rdfs:range rdf:resource="#H"/> </owl:TransitiveProperty> <owl:TransitiveProperty rdf:about="#Cause"> <rdfs:domain rdf:resource="#H"/> <rdf:type rdf:resource="http://www.w3.org/2002/07/ owl#ObjectProperty"/> <owl:**inverseOf** rdf:resource="#Caused_by"/> <rdfs:range rdf:resource="#I"/> </owl:TransitiveProperty> <G rdf:ID="Subsidiary_3"> <Cause rdf:resource="#Subsidiary_4"/> </G> <H rdf:ID="Subsidiary_4"> <Cause rdf:resource="#Subsidiary_5"/> </H>
Reasoning rules used	(1) (?Cause rdf:type owl:TransitiveProperty)∧(?G ? Cause ?H)∧ (?H ? Cause ?I)⇒(?G ? Cause ?I) (2) Cause ≡ Caused_by $^{-1}$ (inverse) (3) (?Cause owl:inverseOf ? Caused_by)∧(?H ? Cause ?I) ⇒(?I ? Caused_by ?H)
Financial diagnosis empirical knowledge after reasoning	<G rdf:ID="**Subsidiary_3**"> <Cause rdf:resource="#**Subsidiary_5**"/> </G> <I rdf:ID="**Subsidiary_5**"> <Caused_by> <H rdf:ID="**Subsidiary_4**"> </Caused_by> </I> <H rdf:ID="**Subsidiary_4**"> <Caused_by> <G rdf:ID="**Subsidiary_3**"> </Caused_by> </H> <I rdf:ID="**Subsidiary_5**"> <Caused_by> <G rdf:ID="**Subsidiary_3**"> </Caused_by> </I>

Table 6
OWL-based financial diagnosis empirical knowledge reasoning contents between the Know-What Layer and Know-Why Layer.

Financial diagnosis empirical knowledge before reasoning	<owl:Class rdf:ID="X"> <rdfs:subClassOf> <owl:Class rdf:ID="Y"/> </rdfs:subClassOf> </owl:Class> <owl:Class rdf:about="#Y"> <rdfs:subClassOf> <owl:Class rdf:ID="Z"/> </rdfs:subClassOf> </owl:Class> <owl:TransitiveProperty rdf:ID="Cause"> <rdfs:range rdf:resource="#Y"/> <rdf:type rdf:resource="owl#ObjectProperty"/> <rdfs:domain rdf:resource="#X"/> </owl:TransitiveProperty> <owl:TransitiveProperty rdf:ID="Part_of"> <rdf:type rdf:resource="owl#ObjectProperty"/> <rdfs:range rdf:resource="#Z"/> <rdfs:domain rdf:resource="#Y"/> </owl:TransitiveProperty> <Z rdf:ID=" **Financial_Abnormal_of_ Sub-conglomerate_2**"> <Y rdf:ID=" **Financial_Abnormal_of_Subsidiary_2**"/> <X rdf:ID=" **Financial_Abnormal_of_Subsidiary_3**"/>
Reasoning rules used	$X \subseteq \exists \text{Cause}.Y \wedge Y \subseteq \exists \text{ part-of}.Z \Rightarrow X \subseteq \exists \text{Cause}.Z$
Financial diagnosis empirical knowledge after reasoning	<owl:Class rdf:ID="X"> <rdfs:subClassOf> <owl:Class rdf:ID="Z"/> </rdfs:subClassOf> </owl:Class> <Z rdf:ID=" **Financial_Abnormal_of_ Sub-conglomerate_2**"/> <X rdf:ID=" **Financial_Abnormal_of_Subsidiary_3**"/> < Cause rdf:resource="# **Financial_Abnormal_of_ Sub-conglomerate_2**"/> </X>

cross-layer empirical knowledge in Section 3.3 are applied to the reasoning between the know-what layer and know-why layer of financial diagnosis empirical knowledge.

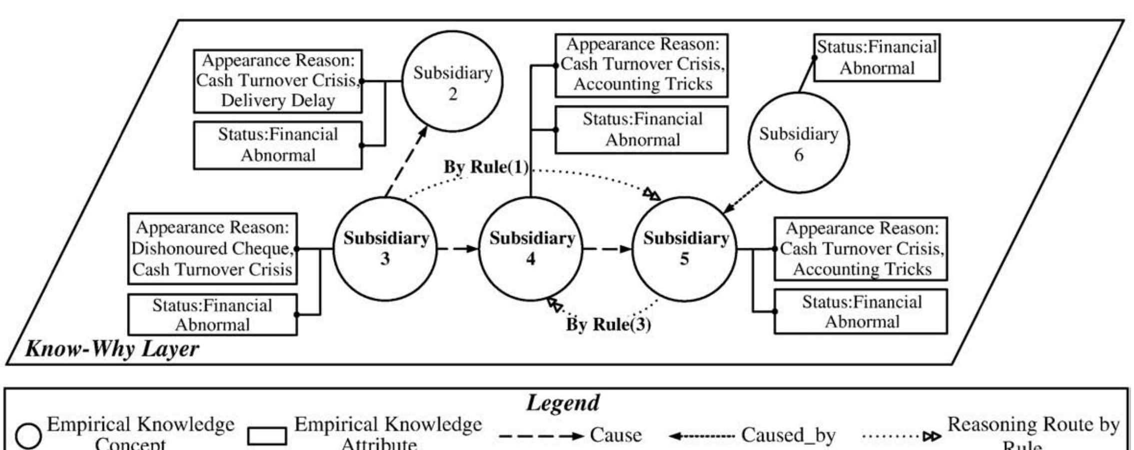

Fig. 19. Ontology-based financial diagnosis empirical knowledge reasoning (Know-Why Layer).

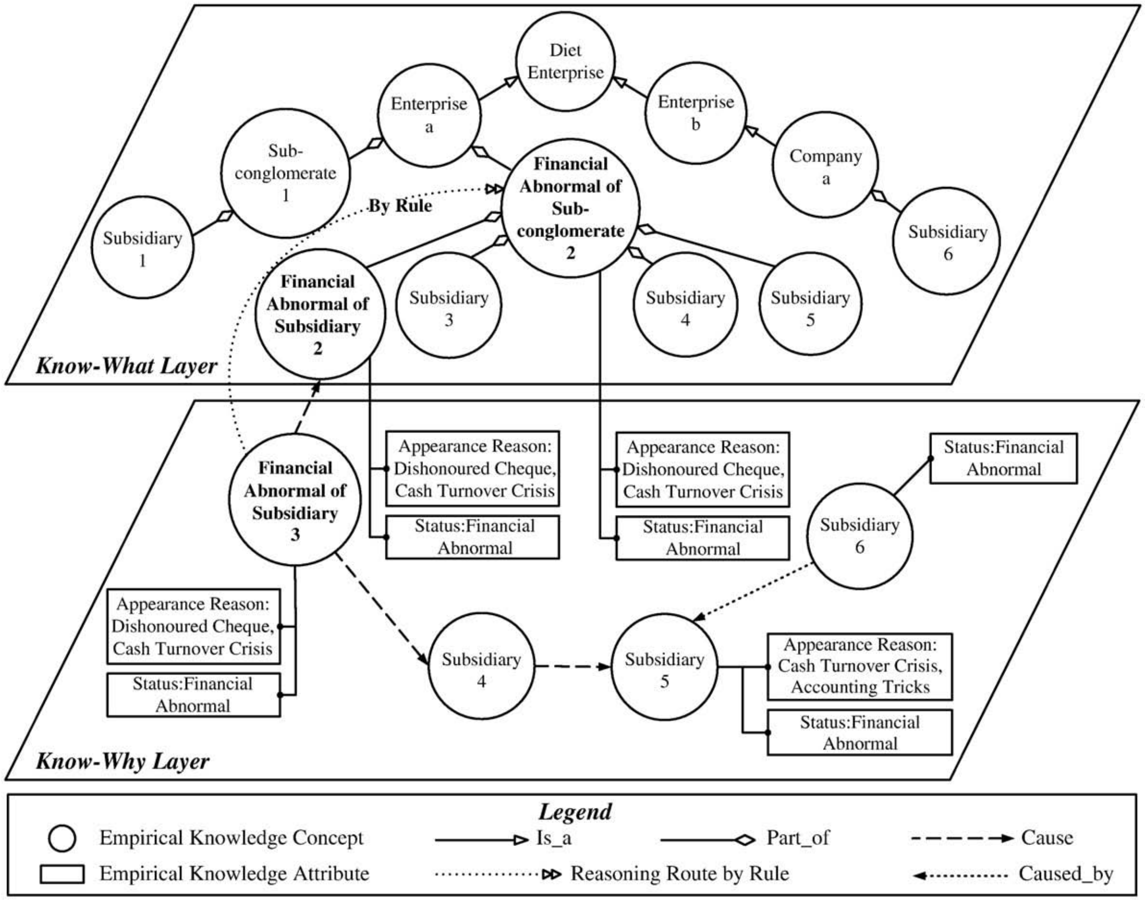

Fig. 20. Ontology-based financial diagnosis empirical knowledge reasoning between the Know-What Layer and Know-Why Layer.

Table 6 lists the partial contents of the reasoning between the know-what layer and know-why layer of financial diagnosis empirical knowledge before and after the executing reasoning process. Meanwhile, a partonomy relationship "Part_of" exists between the empirical knowledge concepts Financial_Abnormal_of_Subsidiary_2 and Financial_Abnormal_of_Sub-conglomerate_2, while a causal relationship "Cause" (Fig. 20) exists between the empirical knowledge concepts Financial_Abnormal_of_Subsidiary_3 and Financial_Abnormal_of_Subsidiary_2. Therefore, a causal relationship "Cause" exists between empirical knowledge concepts Financial_Abnormal_of_Subsidiary_3 and Financial_Abnormal_of_Sub-conglomerate_2 is deduced by the reasoning rule for cross-layer empirical knowledge, as shown in Table 6.

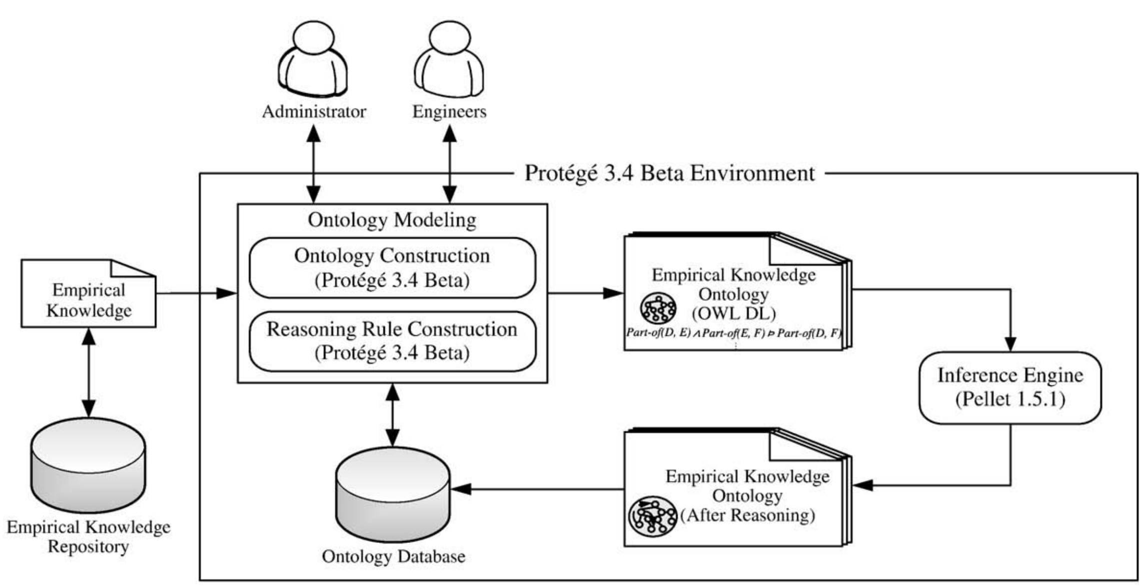

Fig. 21. Mechanism implementation environment.

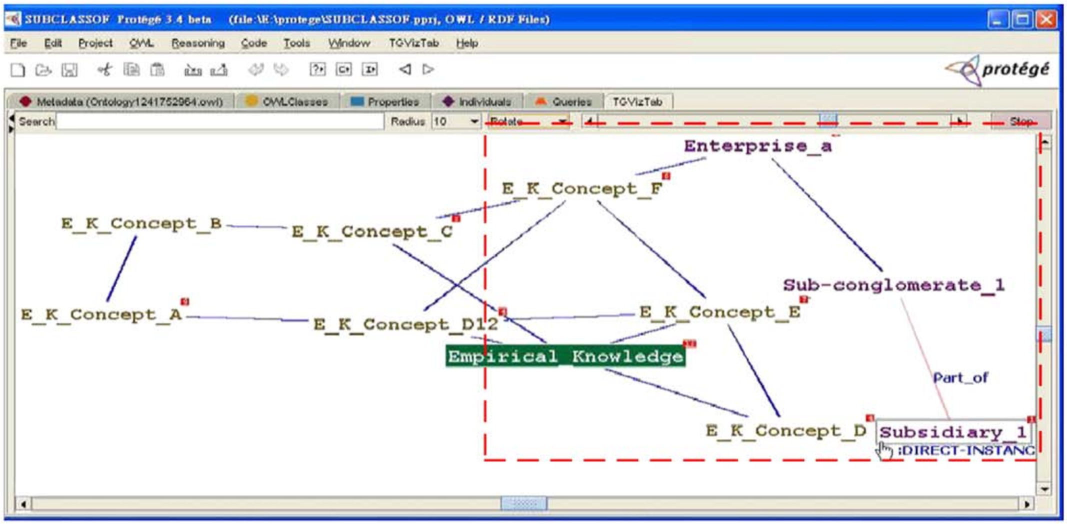

Fig. 22. Financial diagnosis empirical knowledge before reasoning (Know-What Layer).

5. Ontology-based empirical knowledge reasoning mechanism implementation

Based on the above developed method of ontology-based empirical knowledge representation and reasoning, this section uses the software Protégé 3.4 Beta to construct an ontology-based empirical knowledge reasoning mechanism. The implementation environment and results with a financial diagnosis case are described in the following subsections.

5.1. Implementation environment

This study implements a prototype of the ontology-based empirical knowledge reasoning at the Knowledge Engineering and Management Laboratory of National Kaohsiung First University of Science and Technology. The implementation environment was as follows. Computer hardware used was an Intel Core2-2.13G PC. Software was MS Windows XP Professional, Protégé 3.4 Beta (Ontology Construction), and Pellet 1.5.1 (Ontology Inference). Fig. 21 illustrates the mechanism implementation environment, which consists mainly of ontology construction system Protégé, ontology repository, and ontology inference engine Pellet.

5.2. Implementation results

Figs. 22–24 show portions of the user interfaces for the ontology-based empirical knowledge reasoning mechanism. Fig. 22 presents the screen of the know-what layer financial diagnosis empirical knowledge before reasoning, while Fig. 23 presents the reasoning rules in know-what layer of financial diagnosis empirical knowledge. Fig. 24 shows the screen of know-what layer financial diagnosis empirical knowledge after reasoning.

6. Conclusions and further research

This study developed a method for ontology-based empirical knowledge representation and reasoning using ontology techniques to help knowledge requesters to retrieve empirical knowledge for

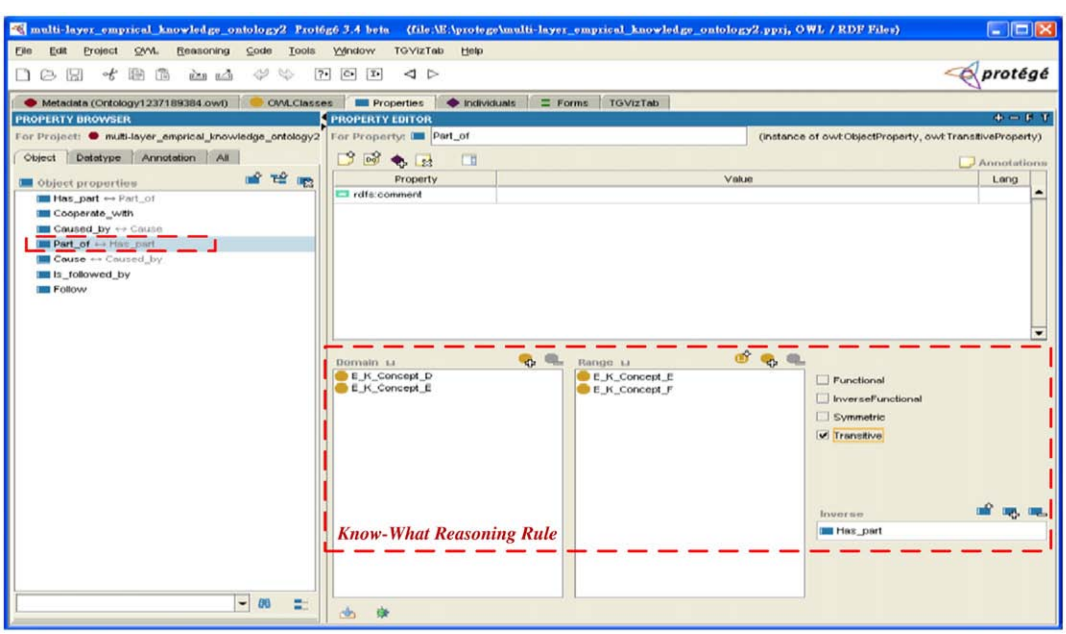

Fig. 23. Financial diagnosis empirical knowledge reasoning rules (Know-What Layer).

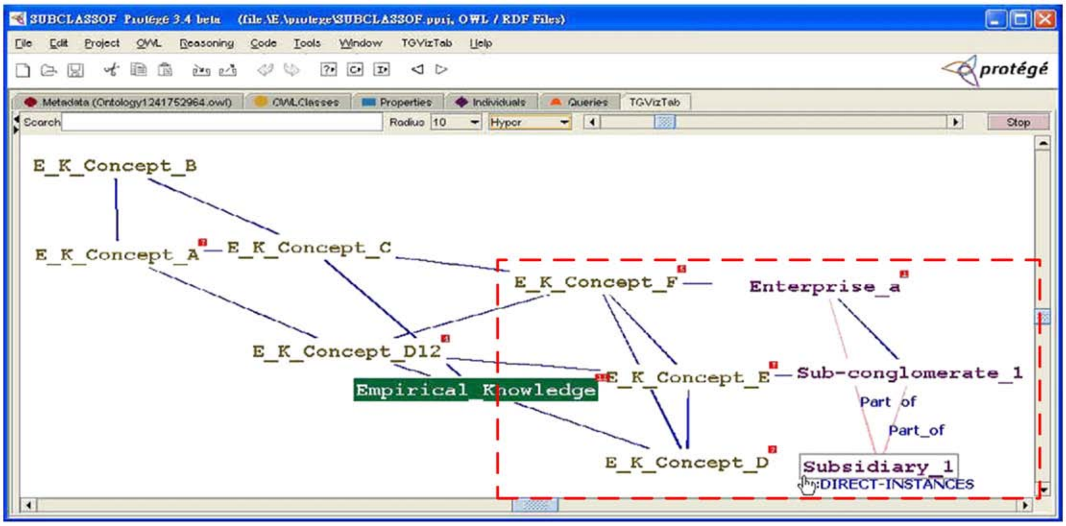

Fig. 24. Financial diagnosis empirical knowledge after reasoning (Know-What Layer).

their problem-solving and decision support. Therefore, the tasks involved in the development include: (i) analyzing characteristics for empirical knowledge, (ii) designing an ontology-based multi-layer empirical knowledge representation model, (iii) designing an ontology-based empirical knowledge concept schema, (iv) establishing an OWL-based empirical knowledge ontology, (v) designing reasoning rules for ontology-based empirical knowledge, (vi) developing a reasoning algorithm for ontology-based empirical knowledge, and (vii) implementing an ontology-based empirical knowledge reasoning mechanism.

The main results and contributions of this study are as follows:

- Ontology-based empirical knowledge representation model: The proposed model is a generic one that can be applied to any knowledge-intensive work for empirical knowledge representation, such as product design knowledge, medical diagnosis knowledge, and software development knowledge.
- Ontology-based empirical knowledge reasoning method: This designed reasoning method can effectively reason empirical knowledge within the same knowledge type or between the different knowledge types for a specific domain, as well as share the retrieved empirical knowledge with the knowledge requesters.

Based on the proposed model and method in this study, the following future research issues are recommended:

- Distributed empirical knowledge representation and reasoning: Given the intensely global competitive environment, management strategies highly prioritize virtual enterprises. In a virtual enterprise, the generated empirical knowledge possesses characteristics of distributed and heterogeneity. Thus, in addition to focusing on how to represent the distributed and heterogeneous empirical knowledge, future studies should as well develop a method for distributed empirical knowledge reasoning.
- Situated empirical knowledge representation and reasoning: Empirical knowledge is associated with situation property. Situated empirical knowledge can comprise basic elements such as spatial relation and temporal relation. Therefore, future studies should consider the situation property of empirical knowledge to develop a method of situated empirical knowledge representation and reasoning in order to deduce a more suitable empirical knowledge that would satisfy the requirements from a knowledge requester under certain circumstances.

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