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A Structural Knowledge Representation Approach in Emergency Knowledge Reorganization

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Abstract

Facing complicate problems in emergency responses, decision makers should acquire sufficient background knowledge for efficient decision-making. Emergency knowledge acquired can be a kind of special product that is transferred among emergency decision makers and functional departments. The processing of knowledge product motivates the emergency knowledge decomposition and event-oriented knowledge integration, i.e. knowledge reorganization. Supported by the semantic power of category theory, the intention of this paper is to seek a new theories and methods for structural knowledge representation. Knowledge Piece, as the component of knowledge product, is discussed through its semantic structure, concept network characters, and functions in this paper. Knowledge Piece is a category with special mathematic characteristics, and also a microcosmic knowledge network or mini ontology. In this paper, we research into the definitions and correlations of knowledge pieces, and apply it to the emergency knowledge reorganization.

Keywords: Emergency Decision-making Support, Structural Knowledge Representation, Category Theory

1 Introduction

Naturally, emergency response needs efficient cooperation among numerous emergency departments [1]. These departments constitute an emergency alliance in which quick and efficient transferring of knowledge is the important basis of background knowledge for emergency decision making. All of these make up of an AKSC for emergency knowledge management [2]. Knowledge is a special product, knowledge product, in the AKSC, because their similarities in the whole process. The structure, characters and functions of knowledge product should be concerned in the first place. The description of knowledge product is the problem of kinds of knowledge representation.

Knowledge representation, just as its name implies, is the representation of knowledge. Z.T. Wang considered knowledge representation in his book named “knowledge engineering” is to study the methods of symbolization and formalization of knowledge. Different fields usually have different views on knowledge representation, and these views generally include cognition view, ontology view, economics view or informatics view. There has emerged a plethora of techniques and literatures for knowledge representation, such as production rule, predicate logic, frame, object-oriented and ontology. These methods of knowledge representation usually have special structure for knowledge processing. Various knowledge representation methods have different exhibitions to the features of structure. The structure of knowledge concerns researches of microcosmic knowledge representation, such as a rule with IF-THEN structure, a record in DB, or a statement in knowledge database. Knowledge is something used to resolve the structureless information, or more concisely, knowledge is kinds of structured information. Developing a mathematical tool to deal with structural properties of knowledge is a basic part of knowledge science [3].

Structural knowledge representation is a subset of knowledge representation, and some researchers give it various definitions. Structural Knowledge is a well-understood concept that means the existence of a well-defined data structure to represent knowledge [4]; it is a set of general principles -- such as physical laws or constitutional frameworks -- against which we are able to define actionable classes [5]; it is transformed into a formal representation (i.e., a knowledge model) that is understandable by computers [6]; and it is the data or information organized in a particular way for future retrieval [7]. Structured knowledge is much more easily stored and accessed, making it much more useful for analysis and problem solving [8], and more reliable than unstructured knowledge. Some researchers studied structured knowledge through different techniques, such as the MOR in [9] and NN-based knowledge structuring in [10-12].

Knowledge piece is special output of knowledge representation. By general admission, knowledge piece is a kind of structural knowledge representation through a micro-perspective. To solve problem, we firstly have no knowledge and gradually acquire some pieces of knowledge by observing new data, and at last arrive at complete knowledge for solving the problem [13]. Knowledge piece is usually required for problem solving [14], causes conflicts in knowledge processing by associating various pieces to one subject [15], consists in contextual information [16], and can be acquired, delivered, created and produced [17]. Josefa first introduces knowledge pieces into to Emergency Knowledge Management System [18]. Knowledge piece should be given certain knowledge granularity, the size of a knowledge piece.

Category theory is a relatively young branch of mathematics designed to describe various structural concepts from different mathematical fields in a uniform way [19], as pointed out by Hoare [20], “Category theory is quite the most general and abstract branch of pure mathematics”. Recently, some researchers associate knowledge management with category theory, for examples, category theory is introduced into object-oriented domain models [21], semantics [22] and ontology [23, 24]. The main contributions of a seminal paper written by R.Q. Lu [3] are the combination of category theory and knowledge science. Lu presented typed category for abstract description of knowledge and knowledge processing.

Base on category theory and typed category theory [3], we have a more exploration on structural knowledge representation and apply it to Emergency Decision-making Knowledge System. Category theory has strong semantic power [25] and can help us to make sense of microcosmic knowledge representation. We employ category theory for descriptions of knowledge piece in emergency knowledge support.

The content of this paper is organized as follows. The motivating case EDKS and its knowledge reorganization requirements are introduced in section 2. In section 3, the emergency structural knowledge representation based on category theory is presented. And In section 4, we give an application of knowledge decomposition in EDKS. Finally, a summary of this paper is given in section 5.

2 The Motivating Case: EDKS

With increasing technology, population and deterioration of the environment, human is threatened by more and more unexpected disasters which include all kinds of terror attacks, epidemics, hurricanes, tsunamis, earthquakes, air crashes, collective food poisoning and industrial accidents. Losses of such disasters are increasing exponentially. It has become urgent things all over world that various countries make well prevention and quick response against such emergencies according to their own circumstances.

Quick and effective decision-making is crucial in emergency responses [1]. After analyzing some typical emergencies, we find that there are usually improper emergency decisions, detrimental measures, and negligent acts which result in disaster expansion. In addition to the reasons of unsuccessful prevention, communication, resource allocation, cooperation, and systemic limitation, one of the main factors related with decision-makers is the speed and quality of acquiring knowledge. Delayed and inefficacy knowledge acquisition can easily interfere effective decision-making and commanding. Therefore, there is knowledge management in decision-making support of emergency responses and such management plays an increasing significant role in emergency information retrieval and decision-making support. Facing emergent incidents, decision-makers need quick knowledge supply which can make an offer of support; but for different incident scenarios, such knowledge is mostly distributed in various emergency documentation such as laws, plans, rules, regulars and other experiences like that.

EDKS, supported by National Nature Science Foundation of China (NSFC), is a project of Emergency DSS for rapid and effective decision-making support in emergency responses.

This project aims at studying and establishing a quick response mechanism to reorganize emergency background information, especially the emergency documentations, into knowledge which is available for decision-making support, as it shown in Figure 1.

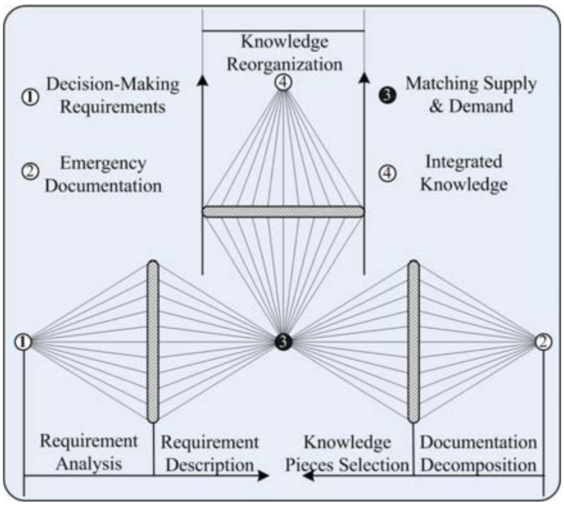

Figure 1. Knowledge Reorganization

In Figure 1, wee can see the process of knowledge reorganization is from decomposing emergency documentation into knowledge pieces, to integrating these knowledge pieces into usable knowledge in accordance with emergent incident requirements by emergency decision-making. In the project EDKS, methods of structural knowledge representation is the first influential factor to such knowledge processing. Knowledge pieces of EDKS come from emergency background information, especially from the emergency documentation [26], and it should be independent in content, integral in semantics and simple topic in domain. So knowledge piece here in emergency knowledge management can not simply be a rule or a record. We introduce a mathematical method of category theory to facilitate structured knowledge.

Knowledge Pieces are also the components of emergency knowledge product [26]; the process of knowledge reorganization is the process of such components' selection, compare, matching and integration. Namely, knowledge piece is the basic element of knowledge product process.

3 Categorical Characteristics of Knowledge Piece

A Knowledge piece (*KP*) is a minimized, structural, discrete and indivisible knowledge component contained specific domain meanings in the process of knowledge reorganization.

Definition 1. A knowledge piece is a Category ***K*** = (*O*, *M*, *T*, *R*) which consist of:
a class of objects *O* which represent concepts in a certain domain;
a class of morphism *M* which represent relationships or actions among *O*;
a class of morphism types *T* which describe the meaning of morphisms;
and a class of composition rules *R* which prescribe the morphism composition.

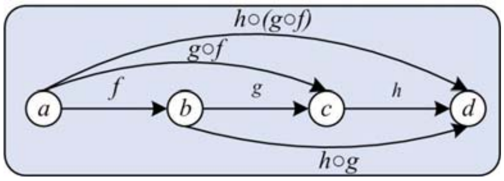

Figure 2. Composition Morphisms in KP

See Figure 2. Each morphism *f* can be written as

$$f : a \xrightarrow{t} b \text{ or } f_t(a,b), \quad (a, b \in O, t \in T), \tag{1}$$

which has one domain, one codomain and one type, written as *dom* (*f*), *cod* (*f*) and *type* (*f*). So *dom* (*f*) = *a*, *cod* (*f*) = *b* and *type* (*f*) = *t* in (1). All the morphisms from *a* to *b* consist of the morphism sheaf which is a set of morphisms has the same domain and codomain. Sheaf shows possible relationships between *a* and *b* in knowledge piece.
For each pair of morphisms $f : a \xrightarrow{t} b$ and $g : b \xrightarrow{s} c$, i.e. *dom* (*g*) = *cod* (*f*), there is possible a composition morphism

$$g \circ f : a \xrightarrow{r} c, (r = s \times t), \tag{2}$$

which should meet the condition that *s* and *t* can be combined in domain knowledge processing according to the composition rule set *R*. The combination of two types of morphisms is a rule of R. Composition morphism means an indirect or potential relationship among these two concepts transferred by intervening concept. It also can be transcendental knowledge apparently.
Sets of concepts with defined relationships between them constitute knowledge pieces. The same concept can be used by multiple knowledge pieces.

For each object *a*, there is only one identity morphism ID_a which has

$$dom\ (ID_a) = cod\ (ID_a) = a, \quad (3)$$

and for each morphism $f : a \rightarrow b$, there are the identity compositions

$$f \circ ID_a = f,\ ID_b \circ f = f, \quad (4)$$

the identity axiom. Identity morphism represents an equivalent auto-morphism, and can be used to describe the reflexive zero-length relationship, like the relationship of inclusion.

For each set of morphisms $f : a \rightarrow b,\ g : b \rightarrow c,$ $h : c \rightarrow d$, it meets the associative axiom:

$$f \circ (g \circ h) = (f \circ g) \circ h. \quad (5)$$

Definition 2. A statement is a triple $S = (s, o, m)$ which consists of a morphism m and its domain s and codomain o in a certain *KP*, see Figure 3.

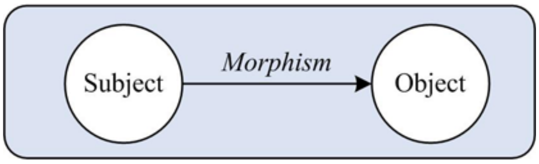

Figure 3. Triple of Statement

Subject and object are the roles of concepts of concrete meanings, and they are the entities which can be perceived, such as organizations, persons, events and available resources. The main difference between subject and object is that subject is active or has strong role in *KP*, whereas object is passive or weak role, that will be depended by the composition rules *R*. *KP* is composed of some Statements by merging their same objects; and a *KP* is a simply connected small network which consists of concept nodes and mapping relationships among them.

Definition 3. A category $\boldsymbol{A} = (O, M, T, R)$ is a subcategory of $\boldsymbol{A'} = (O', M', T', R')$, if $O \subseteq O'$; and for each pair of objects (a, b) ($a, b \in O$), in category $\boldsymbol{A}$, there are

$$M(a,b) \subseteq M'(a,b), \quad (6)$$

$$type(M) \subseteq type(M'). \quad (7)$$

Definition 4. A category $\boldsymbol{A} = (O, M, T, R)$ is a full subcategory of $\boldsymbol{A'} = (O', M', T', R')$, if $O \subseteq O'$; and for each pair of objects (a, b) in category $\boldsymbol{A}$, There is

$$M(a,b) = M'(a,b). \quad (8)$$

The definition of subcategory implies the hierarchical characteristic of *KP*, that is to say, there exists some predefined *KP* categories which can be the general description in a special theme. Consider the category in which the objects are categories and the morphisms are mappings between categories. The morphisms in such a category are known as functors (Steve Easterbrook, 1999) [26]. Functor in category theory is also morphism between categories. Well-established and reusable models can serve as concepts, especially in interdisciplinary knowledge exchange. Functors can be an important way to link the *KP*s for further application, such as assistance of domain ontology construction or knowledge matching.

4 Application in Knowledge Decomposition of Emergency Documentation

4.1 Knowledge Pieces Creation

In the project EDKS, knowledge required by decision-makers is contained in background information, especially in emergency documentation [1]. According to the definitions above, *KP* is a definition, a clause, a flow, a method or a rule, and so as to be considered as the minimized cell of knowledge description and processing. However, the definition of Knowledge Granularity of a *KP* is hard. Usually one paragraph has one main whole idea, and the idea is also described through several objects and their interconnected morphisms. Therefore, we regard one paragraph as a knowledge piece. Knowledge decomposition in this application focuses on the structural representation of emergency documentation, such as laws, plans, regulars.

The following example shows the decomposition of a paragraph in an emergency documentation.

Example. “Centers for Disease Control and Prevention at all levels should establish emergency response teams. The emergency departments at all levels which Participate in monitoring work should strengthen the training and education on the health and epidemic prevention staff. Training and education should make clear the monitoring requirements, including the procedures or requirements of case definitions, reports, investigations and specimen collections. The contents of training and education should also contain departments and personnel responsibilities, particularly strengthening the training on pediatrics, infectious diseases, respiration medicine, prevention and protection, to ensure the required report of suspected cases.” This is a paragraph of “Emergency Plan in Human Infected with Highly Pathogenic Avian Influenza".

We regard the paragraph as a whole knowledge pieces, because the main idea is about the education and training of emergency departments. So it can be described as a knowledge piece $\boldsymbol{K}$, a category, written as $\boldsymbol{K} = (O, M, T, R)$. O is the set of domain concepts which could be extracted. In this example,

$$O = \{o_1, o_2, \cdots, o_8\}, \tag{9}$$

See table 1. Each concept is a domain term, or has a special meaning in the knowledge processing.

Table 1. List of concepts

	Signification
o_1	Centers for Disease Control & Prevention
o_2	Emergency Department
o_3	Health & Epidemic Prevention Staff
o_4	Training
o_5	Monitoring Work
o_6	Work Requirement
o_7	Responsibility
o_8	Report of Suspected Cases

M is the set of relationships on the O, in this example,

$$M = \{m_1, m_2, \cdots, m_{16}\}. \tag{10}$$

This knowledge piece can be visual as a network in figure 4. The real lines are original morphisms which are acquired directly from the paragraph, m_1~m_7. Those broken lines are composition mophisms which are appended through the rules already created, m_8~m_{16}.

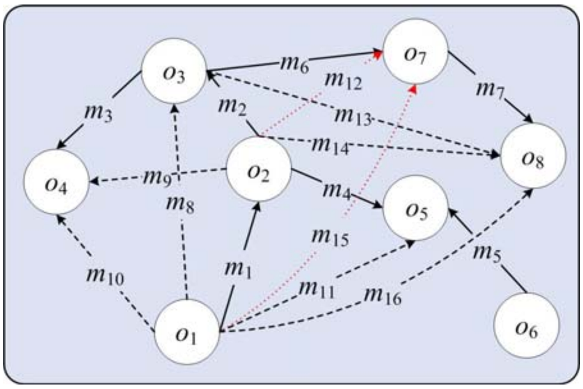

Figure 4. Knowledge Piece

See table 2. Each morphism has a special semantic type which is restricted by its domain and range. Two types can not be equal either in their value or in their domain and range. In this example,

$$T = \{t_1, t_2, \cdots, t_{10}\}. \tag{11}$$

Especially, the dotted lines m_{12} and m_{15} are blank morphism t* with no concrete meaning. Such blank morphism can facilitate the association between these two concepts, so as to experts can append a new type artificially and creatively.

Table 2. Morphism Types

	Value	Domain	Range	
t_1	establish	organization	organization	m_1
t_2	organize	organization	person	m_2
t_3	attend	person	task	m_3
t_4	execute	organization	task	m_4
t_5	restrict	task requirement	task	m_5
t_6	responsible to	person	task	m_6
t_7	include	task	task	m_7
t_8	responsible to	organization	task	m_{14}
t_9	supervise	organization	person	m_8
t_{10}	supervise	organization	task	m_9
t*	blank			m_{12}

Morphism types are organized hierarchically, like the concept hierarchy in domain ontology. The types of a knowledge piece are a subset of the hierarchy types. Two of them can make composition a rule for knowledge storage. In this example,

$$R = \{r_1, r_2, \cdots, r_{14}\}. \tag{12}$$

Table 3. Summary of Rules

	Signification
r_1	$t_9 = C\,(t_1, t_2)$
r_2	$t_{10} = C\,(t_2, t_3)$
r_3	$t_{10} = C\,(t_1, t_{10})$
r_4	$t_{11} = C\,(t_1, t_4)$
r_5	$t_6 = C\,(t_6, t_7)$
r_6	$t_8 = C\,(t_2, t_6)$
r_7	$t_{10} = C\,(t_1, t_8)$

Based on the rules, domain knowledge can be organized orderly, especially the representation of transcendental knowledge. Usually, different persons have different understanding on the process of decomposition; however the composition rules can make them uniform.

It is not always simply connected that all the origin morphisms and composition morphisms constitute a network. See figure 5. Without the morphism m_6, morphisms m_{12} and m_{15} will be inexistence. i.e., we can not give all the morphisms in one knowledge piece even from the creation of origin morphisms. There must have the loss of potential relationships. However, we keep the triple of (o_7, o_8, m_7). This triple is still a part of the knowledge piece. Like a beginner in a domain, what we lost is the understanding on this paragraph, but not all of them.

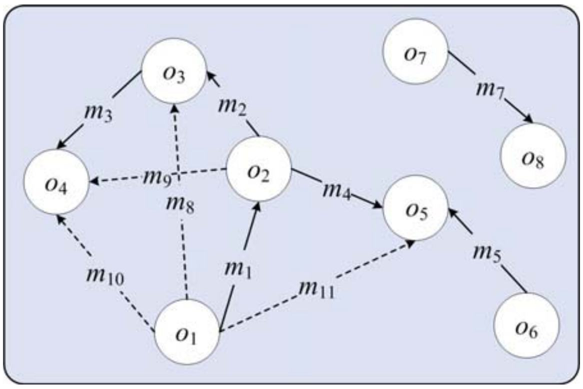

Figure 5. Knowledge Piece

So each part of *KP* has at least one triple. A single concept without any morphism makes no sense.

Like the relationship between Class and object, knowledge pieces also have their hierarchy from abstract definition to concrete instance. These kinds of relationships can be defined by functors. In categorical view, a knowledge piece in a special domain is the subcategory of domain ontology.

4.2 Discussion on Knowledge Pieces and Emergency Ontology

Emergency knowledge piece has a close connection with emergency ontology. The emergency ontology is a kind semantic description on the whole domain concepts and their relationships, while knowledge piece is a semantic structure of a single knowledge point. The knowledge representation of ontology can be relatively perfect, while knowledge piece is unilateral. For better representation of a knowledge piece, the domain ontology is indispensable. On one hand, ontology can guide the construction of knowledge pieces; on the other hand, knowledge pieces also can be pared, abstracted, connected and shaped to facilitate the construction of domain ontology. They are not in the contrary, but interactional and mutually promotive.

Knowledge decomposition depends on domain ontology (emergency ontology) to support the extraction of concepts, morphism types and rules as it is shown in figure 4. Figure 4 shows the process of knowledge decomposition in EDKS.

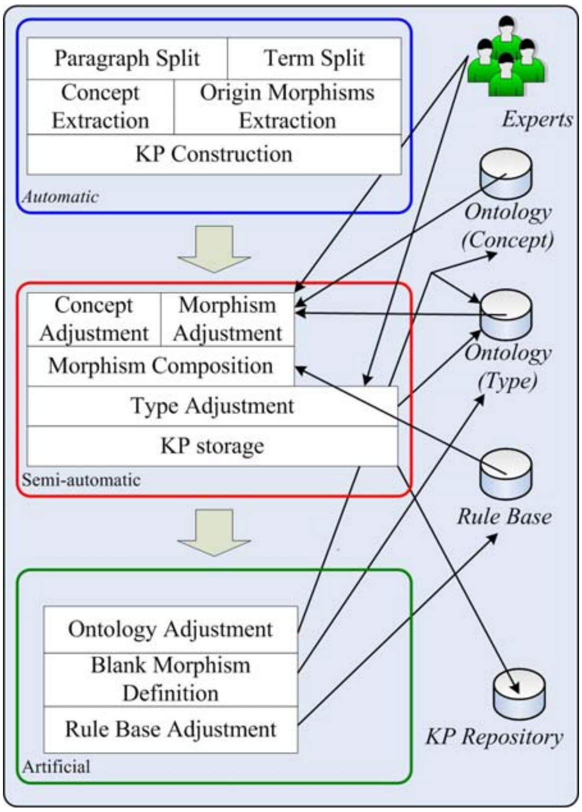

Figure 6. Knowledge Decomposition process

The similarity of two concepts or two morphism types can be measured in the hierarchical definition of emergency ontology. The tightness of them also is countable in event-driven *KP* set. We get together distributed *KP*s from various emergency documentation to compose a certain *KP* set. This set of *KP* is related with the certain emergent incidents and should be organized with integrated form for emergency decision-making support.

Similarity between concept n_1 and n_2 is the distance of these two nodes in emergency ontology, written as

$$S_c(n_1,n_2)= \begin{cases} 0 & |O(n_1)-O(n_2)|=0 \\ \dfrac{|O(n_1)-O(n_2)|}{M}, & |O(n_1)-O(n_2)|<M, \\ 1 & |O(n_1)-O(n_2)|\ge M \end{cases} \quad (13)$$

where M is the threshold of max distance between concepts. In a similar way, similarity between morphism types t_1 and t_2 is defined as

$$S_m(t_1, t_2) = \frac{|O(t_1) - O(t_2)|}{T}, \quad (14)$$

where $|O(t_1) - O(t_2)|$ is the distance between the two morphism types in their hierarchical structure in ontology, T the threshold of max distance between morphisms.

Tightness between concept n_1 and n_2 in a related KP set can be defined as

$$T_n(n_1, n_2) = \sqrt{\left(\frac{C(n_1, n_2)}{C(n_1) + C(n_2) - C(n_1, n_2)}\right) \cdot \left(\frac{1}{k} \cdot \sum_{i=1}^{k} \frac{w_i}{\lambda_i}\right)} \quad (15)$$

$$(T^n(n_1, n_2) \in [0,1]),$$

where $C(n_i)$ and $C(n_1, n_2)$ are the quantities of KP which contains these certain concepts of n_1 and n_2; k the number of possible combination of (n_1, n_2) in discrete KP set, and this combination may be, or may not be a statement; w_i the weight of i^{th} combination $(n_1, n_2)_i$; and λ_i the quantity of edges in the i^{th} combination.

Tightness between morphisms m_1 and m_2 can be defined through the composition rules which consists both of them, written as

$$T_m(m_1, m_2) = \frac{C(m_1, m_2)}{C(m_1) + C(m_2) - C(m_1, m_2)} \quad (16)$$

$$(T_m(m_1, m_2) \in [0,1]),$$

where $C(m_i)$ and $C(m_1, m_2)$ are the quantities of composition rules which contains these certain concepts of n_1 and n_2.

This kind of knowledge representation can facilitate the knowledge integration to measure similarity and tightness among concepts and morphism types, especially in the ontology verification.

5 Conclusion

As we stated above, based on the strong semantic power of category theory and typed category theory, we presented a new approach to the structural knowledge representation. This paper aims at relating category theory with structural knowledge representation to facilitate knowledge reorganization in AKSC. In this paper, Emergency knowledge can be regard as kinds of product, emergency knowledge product. Knowledge reorganization includes knowledge decomposition, knowledge matching and knowledge integration. Knowledge piece representation is the main components of EKP and such a reorganization process which is event-oriented.

We analyzed the mathematic characteristics of knowledge piece, and define it as a category which includes objects, morphisms, types and composition rules. Knowledge piece shows characteristics of network with restricted nodes and edges. We adopted this approach to the application of reorganizing knowledge pieces for event-oriented acquisition of background knowledge from emergency documentation. In this paper, we mainly discussed quantification of knowledge decomposition. Further studies will concentrate on the methods of matching, reasoning and integration of such knowledge pieces.

Acknowledgment

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