Verb Meaning Representation Based on Structured Semantic Components

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Abstract. Meaning representation is a key task in computational linguistics and natural language processing. Many current meaning representation models fail to represent the accurate meanings of some sentences because of the flexibility of natural language meanings. This paper proposes a meaning representation scheme based on semantic components. Through a case study of Chinese strike verbs, *za*(smash) and *tou*(hurl), the paper shows the method of annotating the semantic components for the event participants of each instance of a verb in sentences. The actual meaning of each verb is summarized according to the annotation of semantic features. The change of verb meaning or the generation of new meaning is also explained more reasonably according to the semantic feature annotation proposed in this paper.

Keywords: Meaning representation · Structured semantic component · Semantic role · Dynamic word meanings · Lexical meaning decomposition

1 Introduction

The representation and computation of meanings are fundamental in natural language processing. They are designed to provide linguistic information for downstream NLP tasks such as machine translation and reading comprehension [1,2]. It can be viewed as correlating the forms of natural language to the forms of another metalanguage that can help computers learn the mechanism of the understanding of meanings.

As for a natural language sentence, the metalanguage representing its meaning can be in the form of logical expressions, semantic role labels, abstract meaning representations, frame semantics, etc. Despite their different forms, most of the metalanguages are common in the representation of the propositional meanings of natural language sentences. The propositional concept of a sentence is represented by the verb in the sentence and its semantic relationships with its

theta-roles/semantic roles/frame elements, which are also words and phrases in the sentence. The semantic relationships are represented by semantic labels. This type of metalanguages is based on the semantic relationships between the words in the sentences. It fails to represent sentences like (1).

(1) *fazhan   xinpian,   guang   za   qian   buxing,   hai   yao   za   ren.*
     develop   chip   only   smash   money   unable   also   need   smash   person
     The development of the chip technology needs not only much money but also much human effort.
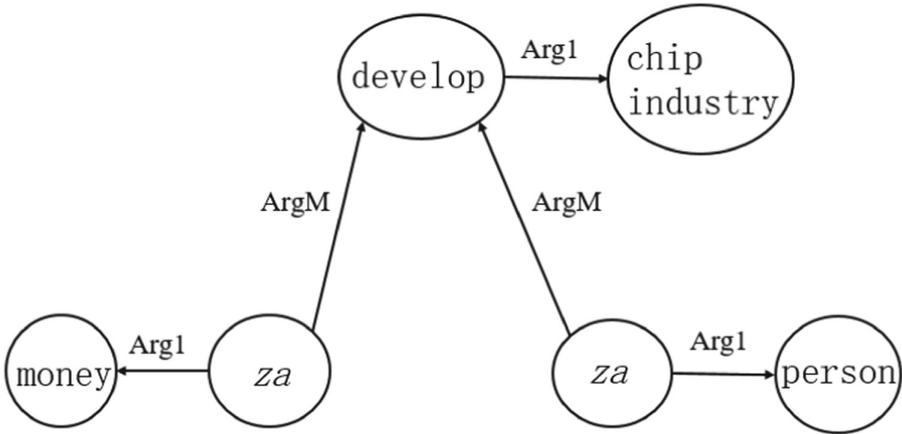

Fig. 1. A way to represent the meaning of (1) in AMR

Take AMR [3] as an example of the type of metalanguage introduced above. If we use AMR, the meanings of the phrases *za qian*[1] and *za ren* in the sentence (1) can be represented as the nouns *qian*(money) and *ren*(person) being the Arg1 or the Arg2 of the verb *za*, as is shown in Fig. 1. The definition of the arguments, recorded in the frameset of Chinese PropBank [4], is shown in Fig. 2. According to the definitions, money and persons are the things being put down or the target of the event. However, the phrases mean to invest much money and human effort instead of putting down a person on something or putting down something on someone. The meaning of *za* in the sentence has changed from its original meaning in Fig. 2. The meaning change of verbs, which is common in natural language, is challenging in natural language processing. This paper points out the flexibility of natural language meanings, analyzes the insufficiency of current meaning representation models based on lexical semantic relationships, and proposes a meaning representation model based on lexical meaning decomposition.

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[1] In this paper, Chinese words transcribed in *pinyin* are in italic, **semantic role labels** are in boldface, and SEMANTIC COMPONENTS are in small capitals.

Frameset: f1

ARG0: *agent*
ARG1: *thing arg0 puts down/dumps*
ARG2: *target*

Fig. 2. The frameset of *za*

2 The Flexibility of Natural Language Meanings

Natural language meanings are flexible rather than fixed semantic units. Synchronically, the meanings of the different instances of a verb may differ in some semantic components. For example,

(2a) *jiefei*   *buting*   *za*   *men, shitu*   *ru*   *shi*   *qiangjie.*
robber   constantly smash door   try   enter   room   rob
The robbers kept smashing at the door in order to rob the house.

(2b) *tangmu*   *buting*   *za*   *men, dan* *limian*   *de*   *ren*   *bu*   *ying.*
Tom   constantly smash door   but   inside   POSS   person   NEG   answer
Tom kept knocking at the door heavily, but people inside did not answer him.

The Chinese verb *za* means hitting something heavily, usually, but not necessarily, with the intention or result of damaging the object. The *za* in (2a) is the typical usage of *za*, where the intention of the action is to damage the *men*(door). The meaning of *za* in (2b) is slightly different from that in (2a). In (2b), the intention of *za men* is to draw the attention of other people in the room. In Chinese linguistic studies and lexical knowledge databases, the two instances of *za* belong to the same sense entry because the difference in their meanings is slight and they do not have distinct syntactic distributions. However, from the perspective of natural language processing, the semantic discrepancy between the two instances needs to be revealed. For example, the *za men* in (2a) can be translated as "smash the door", while the *za men* in (2b) should be translated as "knock at the door heavily". Therefore, it is helpful to describe the semantic discrepancy in machine translation.

Diachronically, a verb may develop into some meanings different from the original ones. For example,

(3) *Huawei*   *za*   *qian*   *yanfa*   *xinpian.*
Huawei smash money develop   chip
Huawei invests a lot of money in the development of chip technology.

In (3), *za qian* means investing a lot of money. This is a newly-developed meaning of *za* and has not been recorded in Chinese dictionaries and lexical knowledge bases such as Chinese Contemporary Dictionary (CCD) or HowNet [5].

The flexibility of word meanings is challenging in natural language processing. As to the above examples, the two instances of *za* in (2) belong to the same sense entry and the meaning of *za* in (3) is not recorded. Thus, knowledge-driven approaches to natural language processing fail to distinguish these meanings. Data-driven approaches may also fail to deal with these meanings accurately because the instances of *za* in (2a) have similar syntactic distributions to the instances in (2b), and the usages of newly-developed meanings are rare. Therefore, the understanding of the flexible word meanings is a challenge to both knowledge-driven and data-driven approaches.

3   The Granularity and Structure of Semantic Role Systems

According to the above discussion, most current meaning representation models are based on lexical semantic relationships, most of which are argument-verb relationships. Therefore, this part discusses the properties of argument-verb relationships in some widely-used meaning representation models and examines their ability to represent flexible verb meanings.

The properties of argument-verb relationships include at least two aspects: the granularity and the hierarchical structure. The granularity of argument-verb relationships refers to the level of generality/granularity of semantic roles. For example, Yuan [6] categorized semantic roles into three levels of granularity, i.e. the macro-level, the meso-level, and the micro-level. According to his categorization, macro-level semantic role systems contain a few semantic roles. For example, the semantic role system of Chinese PropBank is a macro-level one. The semantic roles of *za* in Chinese PropBank are shown in Fig. 2. Meso-level semantic role systems contain about twenty semantic roles. For example, the semantic role systems of the Guidelines for Modern Chinese Predicate Semantic Role Labeling of Peking University [7] and the PKU NetBank [6] are medium-level ones. The semantic roles of *za* in this level of granularity include **agent**, **patient**, and **instrument**. Micro-level semantic role systems contain hundreds of semantic roles. For example, the semantic role system of Chinese FrameNet [8] is a micro-level one. In Chinese FrameNet, *za* has sixteen frame elements, including **Agent**, **Cause**, **Impactee**, **Impactor**, **Impactors**, **Force**, **Instrument**, **Manner**, **Means**, **Period_of_Iterations**, **Place**, **Purpose**, **Result**, **Speed**, **Subregion**, and **Time**.

There are two types of the hierarchical structure of semantic role systems, i.e. the list structure and the tree structure. In the list-structured semantic role systems such as the ones of Chinese PropBank and Chinese FrameNet, a semantic role has no semantic relationships with any other semantic role. In the tree-structured semantic role systems such as the one of PKU NetBank, the semantic

similarity of two semantic roles can be estimated from the hierarchy. For example, in PKU NetBank, **patient** and **target** are both object roles and are core semantic roles, and **instrument** belongs to non-core semantic roles.

The granularity and structure of the semantic role systems in some Chinese semantic knowledge bases are listed in Table 1.

Table 1. The granularity and structure of the semantic role systems in some Chinese semantic knowledge bases

	Macro-level	Meso-level	Micro-level
List structure	Chinese PropBank		Chinese FrameNet
Tree structure		PKU NetBank	

Intuitively, the finer-grained a semantic role system is and the more elaborate its structure is, the more efficient it will be in describing argument-verb relationships. However, the current semantic systems are still not sufficient in describing the flexibility of word meanings. For example, Chinese FrameNet is the finest-grained semantic role system, but the frame elements in Chinese FrameNet cannot distinguish the different meanings of *za men* in (2a) and (2b) and cannot describe the meaning of *za qian* in (3). The PKU NetBank has the most elaborate structure, but as for the sentence (4), it is hard to determine whether *yi ge jiuping*(a wine bottle) is a **patient** or an **instrument**, which indicates that **patient** and **instrument** are sometimes similar. The similarity cannot be reflected by the tree structure of PKU NetBank. Above all, to describe the flexible verb meanings, the semantic representation model needs to have a finer granularity and structure.

(4)   *lvke   ba yi ge   jiuping   henhen   de   za   zai zhantai shang.*
       traveller ba one CL wine.bottle violently ADVM[2] smash at platform   on
       The passenger smashed the wine bottle down on the platform.

4   The Meaning of *za* Represented in Structured Semantic Components

As is discussed above, verb meanings must be fully decomposed in order to reflect the semantic differences among the instances of a verb. Therefore, this chapter proposes a meaning representation method based on structured semantic components and applies this method to the Chinese verb *za* to demonstrate its competence in representing flexible verb meanings.

4.1   The Semantic Components of *za*

The semantic components of *za* can be acquired from either previous work on the verb meanings and semantic roles or from semantic knowledge bases. For

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[2] CL and ADVM refers to Classifier and Adverbial marker.

example, on the lexical analysis of *za*, Jiang [9] decomposed the meaning of *za* into **instrument**: heavy object, **intensity**: heavy, **target**: human or object; on research on semantic roles, Dowty [10] characterized semantic roles in semantic features such as VOLITION, MOVEMENT, BEING AFFECTED, etc.; Yuan [11] distinguished semantic roles by semantic features such as VOLITION, CAUSATION, CHANGE, etc. In semantic knowledge bases, the Semantic Knowledge-Base of Contemporary Chinese of Peking University [12] includes three categories and thirteen subcategories of verbs, such as CHANGE, EXHAUSTION, CREATION, etc. These subcategories are classified according to the semantic attributes of verbs, so they can also be regarded as semantic components. HowNet also contains many sememes that describe the meaning of nouns and verbs, which are also a type of semantic component.

Based on the above research and the sememes in HowNet, sixteen semantic components are selected to describe the meanings of *za*. Their correlation with the coarser-grained arguments of *za* is listed in Table 2.
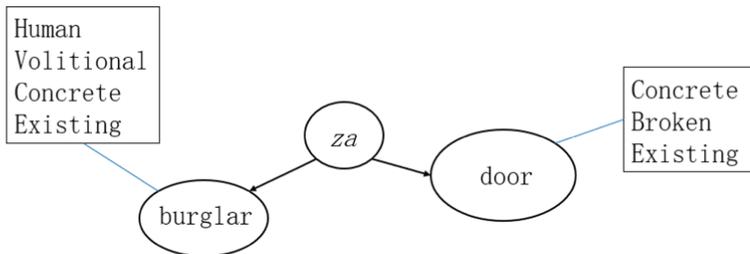
Table 2. The semantic components of *za*

Semantic roles	Semantic components						
Agent	HUMAN	VOLITIONAL	NON-VOLITIONAL	FORCEFUL	MANUAL		
Patient	CONCRETE	ABSTRACT	EXISTING	APPEARING	BROKEN	WORSENED	DEVELOPING
Instrument	MOVING	EXHAUSTIVE	HEAVY	MUCH			

These semantic components can be used to describe the meanings of the events expressed by *za*. For example,

(2a) *jiefei   buting   za   men, shitu   ru   shi   qiangjie.*
     robber constantly smash door   try   enter room   rob
   The robbers kept smashing at the door in order to rob the house.

The meaning of the event expressed by *za* can be represented as Fig. 3. The semantic components of *jiefei*(robber) in (2a) include HUMAN, VOLITIONAL,

Fig. 3. The meaning of the event of *za* in (2a)

FORCEFUL, and MANUAL, which are typical semantic components of the **agent** of *za*. The semantic components of *men*(door) in (2a) include CONCRETE, EXISTING, and BROKEN, which are typical semantic components of the **patient** of *za*.

(2b) *tangmu   buting   za   men, dan limian   de   ren   bu   ying.*
　　　Tom   constantly   smash   door   but   inside   POSS   person   NEG   answer
　　Tom kept smashing at the door, but people inside did not answer him.
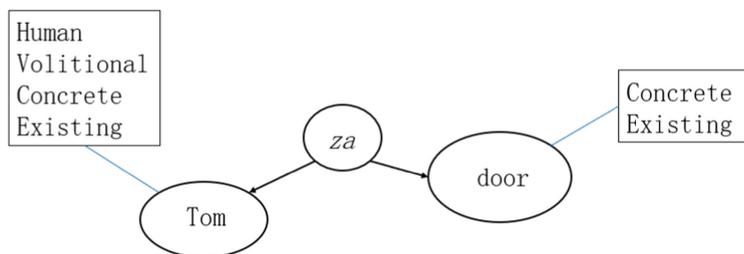
Fig. 4. The meaning of the event of *za* in (2b)

The meaning of the event expressed by *za* in (2b) can be represented as Fig. 4. The semantic components of *tangmu*(Tom) are the same as the ones of *jiefei*(robber) in (2a). The semantic components of *men*(door) do not include BROKEN, which is different from the *men*(door) in (2a).

(3) *Huawei   za   qian   yanfa   xinpian.*
　　Huawei   smash   money   develop   chip
　　Huawei invests a lot of money in the development of chip technology.

The meaning of the event expressed by *za* in (3) can be represented as Fig. 5. The semantic components of *Huawei* do not include FORCEFUL and MANUAL, which is different from the ones of the **agents** in (2a–b). The semantic components of *yanfa xinpian*(develop chip technology) include ABSTRACT and DEVELOPING, which are significantly different from the ones of typical **patients** of *za*. The semantic components of *qian*(money) include ABSTRACT, EXHAUSTIVE, and MUCH, which are also significantly different from the ones of typical **instruments** of *za*.
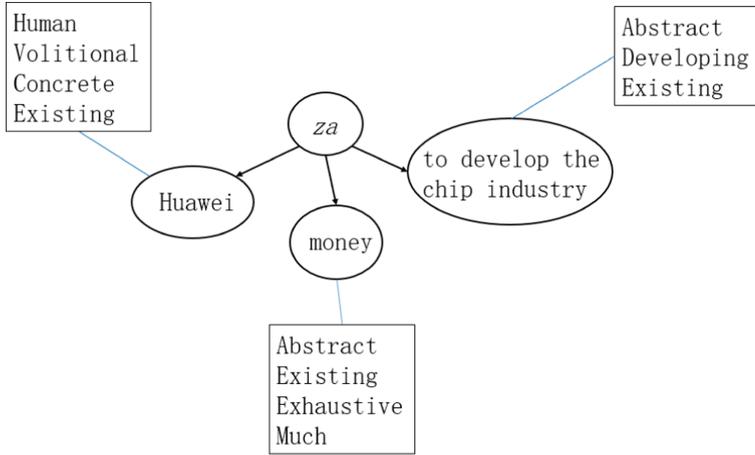
Fig. 5. The meaning of the event of *za* in (3)

The above examples demonstrated the annotation of the meanings of the events expressed by *za*. This method can reflect the semantic discrepancy between the two *men*(doors) in (2a–b) and can describe the meanings of atypical event participants such as *qian*(money) in (3). This method is applied to the corpus of *za*. Fifty sentences containing *za* selected from the CCL corpus [13] are annotated in this method. Each sentence contains one or several participants. The annotation result is shown in Table 3.

The semantic commonalities of different instances of *za*'s event participants can be concluded from the annotation. Then the semantic roles of *za* can be summarized. For example, in Table 3, the semantic attribute pattern of the first row and the one of the tenth row differs only in the attribute of HEAVY and MUCH, so the instances with the two semantic attribute patterns can be concluded as one semantic role. Likewise, the semantic attribute pattern of the third row and the one of the eighth row can also be merged as belonging to one semantic role. The semantic roles concluded in this way are shown in Table 4.

The **agent**, **instrument**, and **hit_object** are similar to the Arg0-2 listed in Fig. 2. The **worsened_object** appears in instances such as *za le zhaopai*(ruined the reputation) and *ba haoshi ban za le*(did a bad job). The **causer** co-occurs with the **worsened_object** and is the subject that non-volitionally causes the **worsened_object** to be worsened. The **result** is the new entity produced in the event of *za*, such as the *bing kulong*(ice hole) in *za bing kulong*(break the ice to form an ice hole). The **investment** and the **invested_object** are the semantic roles used when *za* means investing.

Besides the typical semantic roles, *za* also has some atypical semantic roles. For example,

Table 3. The semantic components[a] of the event participants of *za* in the corpus and the number of their instances

Semantic component																Number of instances
a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	
					+		+		+							18
						+	+			+						15
+	+		+	+	+		+									14
					+		+					+		+		7
					+		+		+					+		6
+	+				+		+									5
					+			+			+					4
+	+		+	+	+		+								+	4
+					+		+									4
+		+			+		+		+							2
					+		+		+				+	+		2
					+		+					+	+	+		2
					+		+					+				2
					+		+									2
						+	+									2
					+		+		+					+		1
					+		+		+			+		+		1
					+		+				+					1
						+	+				+					1
						+	+						+		+	1

[a] a. HUMAN; b. VOLITIONAL; c. NON-VOLITIONAL; d. FORCEFUL; e. MANUAL; f. CONCRETE; g. ABSTRACT; h. EXISTING; i. APPEARING; j. BROKEN; k. WORSENED; l. DEVELOPING; m. MOVING; n. EXHAUSTIVE; o. HEAVY; p. MUCH

Table 4. The semantic roles of *za*, their semantic components, and the number of their instances

Semantic roles	Semantic components																Number of instances
	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	
hit_object	+/−		+			+		+	+				+/−		+/−		27
agent	+	+		+	+	+		+					+/−			+/−	17
destroyed_object							+	+			+					+/−	16
instrument						+		+					+		+		10
result						+		+	+			+					5
causer	+		+			+		+								+/−	4
investment							+	+						+		+	1
invested_object							+	+				+					1
hit_object (atypical)						+		+				+					1
instrument (atypical)						+		+					+				1

(4a) *renren*   *dou*   *pa*   *shuye* *luo*   *xialai*   *za*   *po*   *tou,* *kandao*
      everyone   all   fear   leaf   fall   down   smash broken head   see

Everyone fears that their heads will be smashed by fallen leaves

      fubai   *xianxiang*   *buwenbuwen.*
      corruption phenomenon   indifferent

and chooses to be indifferent to corruption.

(4b) *zhe*   *laotouzi*   *gei*   *ta*   *za*   *diji.*
      DEM_DIST   old.man   give   3sg   smash   foundation

This old man is smashing the foundation of the house for him.

In (4a), the *shuye*(leaf) is an atypical **instrument** because it is not HEAVY. The semantic attribute BROKEN of *tou*(head) is profiled, so the meaning of the **instrument** can be different from typical ones. In (4b), the *diji*(foundation) is an atypical **hit_object** because it is not BROKEN. The semantic attribute FORCEFUL of *zhe laotouzi*(this old man) is profiled in this sentence. The annotation of the semantic attributes can reflect the accurate meaning of the atypical semantic roles.

The sense entries of *za* can be concluded from the co-occurrence of its semantic roles. In the corpus of *za*, the **hit_object** co-occurs with the **instrument**, **result**, and the **agent**; the **worsened_object** co-occurs with the **causer**; the **investment** co-occurs with the **invested_object** and the **causer**. The three co-occurrence patterns correspond to three sense entries. The first can be concluded as "hitting an object heavily with a heavy object", which is the original and most commonly-used meaning of *za*; the second can be concluded as "destroying abstract properties"; the third can be concluded as "investing". The second and the third sense entries are usually not recorded in lexical knowledge bases and dictionaries. The correspondence between *za*'s sense entries and semantic roles, and semantic roles and semantic components, are shown in Fig. 6. Only the typical semantic roles and part of the semantic components are exhibited in the Fig. 6.
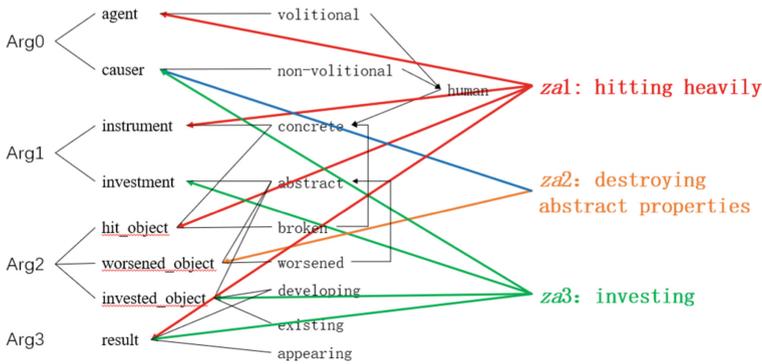

Fig. 6. The sense entries, semantic roles, and semantic components of *za*

The sense entries can be divided further according to the syntactic distributions. For example, as to the first sense entry of *za*, the usage where the **agent** appears can be defined as "hitting something with a heavy object"; the usage where the **instrument** appears in the sentence but the **agent** does not can be defined as "a heavy object falling down"; the usage where the **hit_object** appears alone can be defined as "be broken". The above usages corresponds to the first and the second sense entry of *za* in CCD.

The sense entries concluded by the method proposed above are more accurate and conform better with the use of *za* in natural language that the ones in dictionaries. For example, the third sense entry in this paper is not included in CCD; the second sense entry in this paper is defined as "destroying an abstract object", but in CCD it is defined as "failing", which is a unary verb, indicating that only the **worsened_object** appears in the sentence. However, in the corpus of *za*, there are only five usages where the **worsened_object** appears alone but nine usages where the **worsened_object** co-occurs with the **causer**.

4.2   The Hierarchical and Metaphoric Structure of the Semantic Component System

The semantic relationships between the semantic components can be further discovered. The relationships include the entailment relationship and the metaphoric relationship.

The entailment relationship can be discovered either from common knowledge or from the annotation. For example, if a participant has the semantic component FORCEFUL, he must also have the semantic components HUMAN and VOLITIONAL, which means FORCEFUL entails HUMAN and VOLITIONAL. In the annotation of the event participants, if a semantic component A always co-occurs with another semantic component B, it can be inferred that A entails B. For example, the column d in Table 3 always co-occurs with the columns a and b, indicating that FORCEFUL entails HUMAN and VOLITIONAL.

The metaphoric relationship can be discovered from the development of word meanings. For example, in the development from the first sense entry of *za* to the second and third sense entries, the semantic components CONCRETE and BROKEN of the **hit_object** turned into the ABSTRACT and WORSENED of the **worsened_object**; the HEAVY of the **instrument** turned into the MUCH of the **investment**. In linguistic research, the metaphoric relationship between CONCRETE and ABSTRACT is often mentioned [14,15], but the metaphoric relationships between more specific semantic components such as HEAVY and MUCH is less noticed systematically. The entailment and metaphoric relationships between semantic components are demonstrated in Fig. 7.
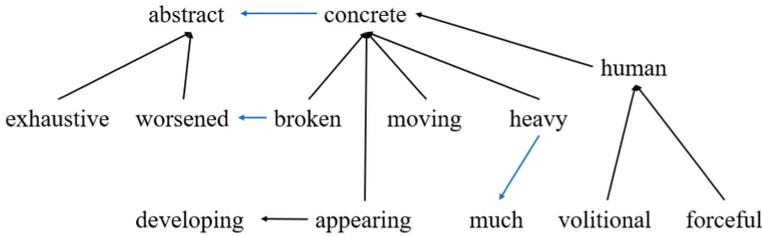
Fig. 7. The hierarchical and metaphoric structure of the semantic component system

The structure of the semantic component system can reflect the significance of different semantic components. For example, CONCRETE, ABSTRACT, HUMAN are higher-level semantic components. They are more general in meaning. If their values change in the verb meaning development, the values of many other semantic components may also change, and the meaning of the verb may change significantly. For example, the CONCRETE of the **hit_object** turns into ABSTRACT of the **worsened_object**. The values of many other semantic components also change, such as BROKEN and HUMAN. FORCEFUL and MANUAL are lower-level semantic components. They are more specific in meaning and can distinguish a language unit from the others. If two event participants differ in the lower-level semantic components, they should be categorized as different semantic roles. For example, the **agent** and the **causer** are only different in the values of FORCEFUL and MANUAL, but the co-occurrence with other semantic roles also indicates that they should be treated as different semantic roles.

The structure of the semantic component system can also describe and predict the verb meaning development. For example, the Chinese verb *kang* originally means carrying heavy objects with one's shoulders. Recently, it developed into the meaning of undertaking much abstract objects such as debt, blames, or responsibilities. For example,

(5) *yuehan   wei   qizi   kang   xia   wubaiwan   zhaiwu.*
       John   for   wife   shoulder under five.million   debt
   John afforded $5 million in debt for his wife.

This meaning of *kang* has also not been recorded in CCD, but it can be predicted by the structure of the semantic component system.

5   The Application of the Structured Semantic Components on Other Verbs

The above method can describe the meanings of other verbs and explain and predict their meaning development. For example, the Chinese verb *tou* has eight

sense entries in CCD, two of which are close to *za* in meanings. One is throwing something at a target. It is similar to the first sense entry of *za* in that it also expresses hand motions. The other is putting something into a place. It is similar to the third sense entry of *za* when it co-occured with *qian*(money).

The meaning of *tou* cannot be accurately expressed only by the sixteen semantic attributes listed above. Five more semantic components need to be added, including q. ALOFT, r. FROM, s. ARRIVE, t. GIVE, u.GET. The latter four are binary semantic components indicating the relationships between different event participants.

The meaning of some semantic roles of *tou* is listed in Table 5 and 6. The other semantic roles and semantic components are omitted in the table because they are rarely used and not relevant to the meaning of *za*.

Table 5. The unary semantic components of the semantic roles of *tou*

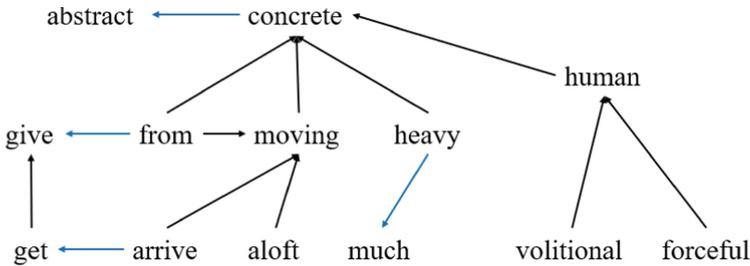| Semantic roles	Semantic components									
	a	b	c	d	e	f	g	h	m	q
thrower	+	+		+	+	+		+		
thrown_object						+		+	+	+
thrown_target	+/−		+			+		+		
mover	+	+			+	+		+		
moved_object						+		+	+	
moved_target						+		+		
giver	+	+			+/−	+		+		
given_object						+/−	+/−	+	+/−	
receiver	+/−	+/−	−/+			+		+		
starting_point						+		+		
finishing_point						+		+		

The unary semantic components can distinguish most semantic roles of *tou*, but they cannot distinguish the **moved_object** and **given_object**, and the **starting_point** and **finishing_point**. Binary semantic components are needed to help distinguish these semantic roles. The binary semantic components of some pairs of semantic roles are listed in Table 6.

Three usages of *tou* can be summarized from the semantic components. The first is throwing, which is its original meaning. The second is moving and the third is transferring.

The structure of the semantic component system can be extended from the meaning of *tou*. For example, ALOFT entails MOVING, FROM and ARRIVE entail CONCRETE, and there are metaphoric relationships between ARRIVE and GET, FROM and GIVE. A part of the extended structure of semantic component system is shown in Fig. 8.

Table 6. The binary semantic components of some semantic roles of *tou*

role1	role2	Semantic components			
		r	s	t	u
starting_point	thrown_object	+			
finishing_point	thrown_object		+		
moved_target	moved_object		+		
giver	given_object	+		+	
receiver	given_object		+		+

Fig. 8. The hierarchical and metaphoric structure of the extended semantic component system

6   Conclusive Remarks

Verb meanings are flexible. Diachronically, the meaning of a verb may change; synchronically, the meaning of a verb may be skewed from its canonical meaning according to the context. However, current meaning representation models that are based on semantic relationships between words and their lexical knowledge bases are static and coarse-grained. Only a part of the canonical verb meanings are recorded in the knowledge bases. Therefore, to help the static meaning representation model capture the dynamic verb meanings, the argument-verb relationships in the model must be fine-grained enough. In this paper, representing the meanings of the event participants in semantic components proves to be a feasible approach.

This paper takes the Chinese verb *za* as an example, demonstrates the flexibility of its meaning, and labels some instances of the verb in semantic components. The annotation indicates that the semantic representation based on semantic components can reveal the semantic discrepancy between different semantic role instances and describe the meaning of atypical semantic roles. The semantic roles and sense entries of *za* can be summarized from the annotation. The method can also apply to other verbs such as *tou*.

The method is still under theoretical discussion, and its effect needs to be proved by more annotated data on a variety of verbs. The selection and definition of the semantic components are also to be explored.

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