A Semantics Oriented Grammar for Chinese Treebanking

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Abstract. Chinese grammar engineering has been a much debated task. Whilst semantic information has been reconed crucial for Chinese syntactic analysis and downstream applications, existing Chinese treebanks lack a consistent and strict sentential semantic formalism. In this paper, we introduce a semantics oriented grammar for Chinese, designed to provide basic supports for tasks such as automatic semantic parsing and sentence generation. It has a directed acyclic graph structure with a simple yet expressive label set, and leverages elementary predication to support logical form conversion. To our knowledge, it is the first Chinese grammar representation capable of direct transformation into logical forms.

Key words: Chinese Semantic, Semantic Representation, Chinese Treebanking

1 Introduction

Chinese treebanking has been a much debated issue, largely due to the uniqueness of the language [1–5]. Similar to English, Chinese is an isolating language, for which meaning is defined over relatively rigid phrase structures, rather than rich morphology [6]. On the other hand, Chinese has relatively much less function words, and much more means of phrase construction, which makes its structural disambiguation a more challenging task. Much often, the resolution of syntactic ambiguities needs to resort to semantic interpretations.

Figure 1 shows an example, where the syntactic structure of "外商 (foreign capital) 投资 (investment) 企业 (business)" can be determined *only* by referring to the meaning of content words in the rest of the sentences. According to phrase structure syntax [2], the two sentences can be treated either as topicalized sentences, in which the underlined phrases serve as the topic, or as subject-predicate sentences that have a sentential (NN-VA) predication.

The example reflects the degree of flexibility in Chinese sentence construction, where patterns such as topicalization and pro-drop are quite common. As a

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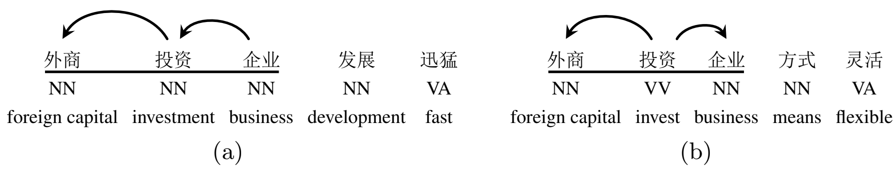


Fig. 1. Syntactic ambiguities requiring semantic knowledge to resolve.

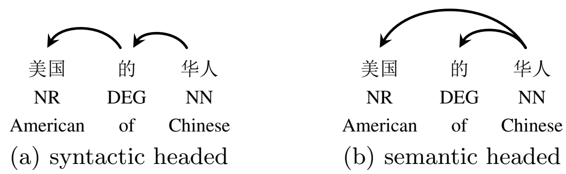


Fig. 2. An example contrast between syntactic and semantic headedness.

result, the best accuracies of Chinese syntactic parsing is significantly below those of English [6–9], despite availability of large-scale syntactic treebanks. This makes the extraction of semantic information less accurate, given the fact that semantic role labeling is commonly performed on top of syntactic structures.

There have been attempts at constructing Chinese treebanks that are more semantics driven [10, 4]. By defining semantic relations directly over words, these treebanks allow statistical parsers to build semantic links directly from POS-tagged data, hence avoiding error propagation in pipeline syntactic and semantic analysis. Such treebanks typically differ from their syntactic counterparts in two ways. First, head words in dependency arcs are semantic rather than syntactic. Second, dependency labels are defined over semantic instead of syntactic relations.

Figure 2 shows an example of syntactic and semantic headedness. In (a), "美国 (American)" takes the syntactic head "的 (of)", which governs the syntactic constituent DCP. In (b), "美国 (American)" takes the semantic head "华人 (Chinese)" instead. This semantic headed link form is relatively more informative to downstream applications such as machine translation [11]. It also enjoys robustness over paraphrasing. For example, the three phrases "美国 (American) 华人 (Chinese)", "美国 (American)的(of) 华人 (Chinese)" and "在 (at) 美国 (American) 的 (of) 华人 (Chinese)" have very different syntactic structures, with the underscored modifier phrase being NP, DCP and LCP, respectively [12]. However, in the semantic headed format, the link between '美国 (American)" and "华人 (Chinese)", which bares the invariant meaning, remains the same across the three paraphrases.

These dependency treebanks, however, have two significant limitations. First, they are constructed ad-hoc over syntactic treebanks, and do not have a strict separation between syntax and semantics. Take Che et al. [4] for example, they offer 123 detailed labels to replace the original syntactic labels, making disam-

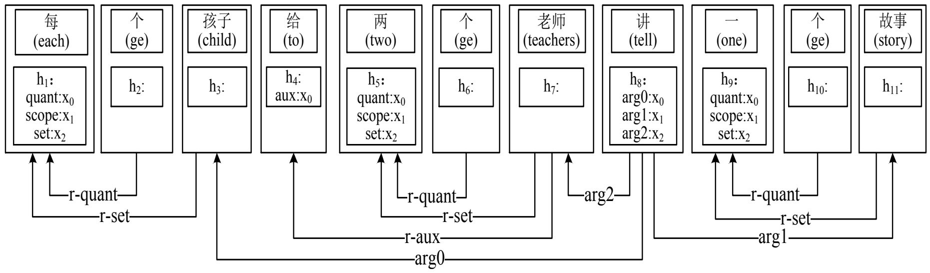


Fig. 3. The semantic representation for the Chinese sentence "每个孩子给两个老师讲一个故事 (Every child tells a story to two teachers)"

biguation difficult[1]. On the other hand, these labels are ad hoc, and ones such as "attribute" and "coordinate" can be treated as syntactic.

Second, lack of a strict semantic formulation makes these treebanks unsuitable for wider downstream semantic tasks such as logical inference. In contrast, even syntactic formulations including CCG [13], LFG [14] and HPSG [15] allow the transformation of syntactic derivations into logical forms.

Driven by the above needs, we propose a semantics oriented grammar formalism for Chinese treebanking. The formalism uses a direct acyclic graph to represent sentential semantics, for which existing parsing technology is available [16]. In contrast to the aforementioned Chinese treebanks, the formalism is constructed following a strict semantics structure and allows transformation into logical forms. In addition, the number of arc labels is much smaller, allowing efficient parsing yet maintaining semantic expressiveness. We adopt Propbank-style predicate argument structures, yet extend elementary predications from verbs to quantifiers, adjectives and adverbs.

2 The Semantic Representation

The semantic framework we propose is lexicalized. However, instead of building semantic relations on the lexicons directly, we first project each word in the input sentence to an *elementary predication* (EP). The concept of EP is proposed in Minimal Recursion Semantics (MRS) [17] as the primary units of computational semantics, where each word can correspond to different EPs under different contexts. We adopt this notation. The semantic links in our framework are defined over EPs, as illustrated by the example in Figure 3.

2.1 Elementary Predication

EPs serve as the basic semantic frames for lexicons. By transforming words into EPs, semantic ambiguities such as predicate-argument structures, quantifier

[1] See Related Work for a more detailed discussion.

scopes and pronominal references can be resolved more easily.

Definition 1 (Elementary Predication (EP)).
An elementary predication is composed by the following three components:

- Predicate: usually the word itself.
- Handle: the label of the EP.
- Arguments: each EP can have a list of zero or more variables arguments. These arguments denote the predicate's core semantic role. Each argument has a semantic label that describes its relation to the predicate.

Each EP can be written as $\textit{predicate:handle}(\textit{label}_0{:}x_0, \cdots, \textit{label}_n{:}x_n)$. For example, the word "讲 (tell)" in the example sentence can be projected into the EP: "讲:h_8(agent:x_0, target:x_1, content:x_2)", as shown in Figure 3. The EP arguments can be none also, when the word does not accept any arguments at all (e.g., nouns denoting concrete objects).

EP structures are very similar to the predicate-argument structures in Propbank [18] and Chinese Propbank [19], but they have two main differences. First, the predicate of an EP is more general than that of Propbank. Propbank models only the propositions in a sentence, while EP regards every word in a sentence as a potential predicate, including quantifiers, adjectives, adverb, and expletives. In this way, EPs can handle more semantic relations than Propbank. For example, when we encode the scope attribute as a core semantic role of numeral words, numeral words' quantifier scopes can be expressed.

Second, EPs stress the integrity of their composition. A word can have only a finite number of EP structures. In a sentence, one instance of a word can take only one EP. If the value of a semantic role in an EP cannot be assigned, the semantic structure is incomplete. In contrast, without the EP structure, a semantic role labeler can neglect the framesets that Propbank defines, resulting in incomplete predicate structures or confused ellipsis phenomena.

Compared with the EPs in MRS [17], our EPs are much simpler. For example, we do not have the scope attribute as an indispensable element for every EP, since in most cases the scopes are directly reflected by the semantic relations. For those words that do have scope ambiguities, we add the scope as an argument in their EPs.

2.2 EP Arguments

There is a fixed set of EP arguments in our representation, as listed below.

- Proposition. We define the arguments of proposition words using the same method as Propbank. There are five core arguments and 14 function arguments. For more detailed descriptions, refer to Xue and Palmer [19].
- Auxiliary. We define a special argument named *aux* for the Chinese words that do not directly bare a meaning in the sentence. For example, punctation words, "的 (de, possessive marker)" and "被 (bei, passive marker)" are of this type. The aux links do not bare any meanings. However, the existence of auxiliary words influences the semantic roles of other words.

– Quantifier. We have three arguments for quantitative words: *quant*, *scope* and *set*. The Chinese measure words are special and seldom exist in other languages. For example, the bold words in "一**棵**树 (a tree)" and " 一**个**人 (a person)" are measure words. We use *quant* to denote their semantics. The words with the most scope ambiguities are probably quantitative words, and we add the argument *scope* to these words. The argument *set* is used to denote the nominal word that the quantifier modifies.
– Coordination. Conjunction words such as " 和 (and)" and " 或 (or)" are not semantic heads in the formalism. We use two arguments, *conj* and *entity*, on the right-most content word of the conjunction phrase to denote its semantics. *conj* denotes the conjunction words, while *entity* denotes coordinated entities.
– Anaphora. We use the argument *refer* to denote the reference to a pronoun's semantic head.
– Interrogative. We define two arguments to represent the semantic of interrogative words in a question, namely *interrog* and *answer*. The argument *interrog* is defined on the main propositional words of a sentence, and links to the interrogative words, while the argument *answer* denotes any answer found in the current context.

The six categories cover most semantic relations of Chinese sentences. Due to inherent ambiguities and mistakes in statistical parsing, we allow some arguments to be underspecified. For example, the scope argument of quantifiers can be unfilled in a sentence. We will give detailed examples of typical arguments in Section 3.

2.3 The Sentential Structure

The building of dependencies is the assignment of arguments for EPs, where an EP may have multiple heads. Definition 2 gives a formal definition of the formalism.

Definition 2 (Sentential Structure).
The grammatical structure for a given input sentence is a labeled direct acyclic graph (DAG) $G = (V, E, R)$, which satisfies the following constraints:

– $V =< \mathrm{EP}_1, \cdots, \mathrm{EP}_n >$. The nodes of the graph G are a sequence of EPs. Each word in the sentence is mapped into an EP. Thus the number of nodes in G is equal to the number of words in a sentence.
– Each edge e_k between EP_i and EP_j $(i \neq j)$ in E is associated with an argument (label_m:xm). It serves as a directed semantic link from EP_i to EP_j, with EP_i being the head. The label of e_k is either label_m or r-label_m. If the argument of the edge belongs to EP_i, then the e_k is labeled as label_m, otherwise it is labeled r-label_m, indicating an argument direction that is reverse to the head→modifier direction.

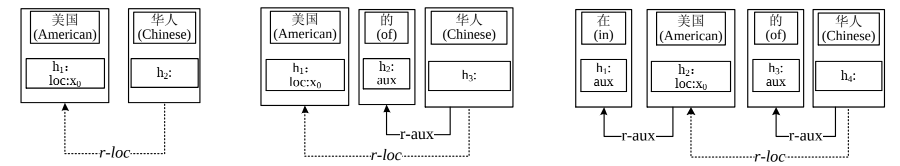
This formalism builds role-filling links between EPs. Each edge gives the true value for one argument of an EP. For example, in Figure 3, the edge "老师:h_7()" $\xleftarrow{\text{arg2}}$ "讲:h_8(arg0:x_0, arg1:x_1, arg2:x_2)" assign the value "老师:h_7()" to the argument *target:*x_1 of h_8. The directed acyclic graph constraint can prevent infinite loops in the determination of the value of an EP, and allow efficient parsing algorithms to be applied.

2.4 Logic Interpretation

In the same way as syntactic grammatical relations, semantic relations from our formalism can be used as features for downstream applications, such as question answering and machine translation. As discussed in the introduction, semantic relations can potentially be more informative than their syntactic counterparts, and our grammar shares the motivation of Che et al. [4] in exploiting this advantage. One important advantage of our grammar is the support of logic interpretation, and hence it can also be used for tasks such as parsing into logical forms [20] and surface realization [21]. In this section, we illustrate how the EP-based structures can be transformed into Neo-Davidsonian first-order logic. Similar methods can be used for transformation into other logical forms.

The conversion from the DAGs into logic is rather straightforward, thanks to EPs. In particular, a propositional EP is associated with a lambda calculus expression, where the λ-free variable is used to represent an event, and a set of (zero or more) λ-bound variables are defined for its arguments. In the example in Figure 3, h_8 for "讲 (tell)" can be associated with the lambda term $\lambda x_0 \lambda x_1 \lambda x_2 \exists e_0\ \mathit{tell}(e_0) \wedge \mathit{arg0}(e_0, x_0) \wedge \mathit{arg1}(e_0, x_1) \wedge \mathit{arg2}(e_0, x_2)$.

EPs for nominal contents are associated with only bound variables. For example, h_{11} for "故事 (story)" can be associated with the lambda term $\lambda y_0\ \mathit{story}(y_0)$. Quantifier EPs are associated with logical quantifiers and a constant term 1. For example, h_5 for "两 (two)" can be associated with the term $2x.1$. EPs for measure words and auxiliaries are correlated with the constant term 1 in first-order logic. A sentential logical expression is derived by traversal of the acyclic dependency graph, performing logical conjunction and beta-reduction on each link. Scopes of quantifiers are decided by the *scope* links, but can also be underspecified when the link is undecided. For example, the *r-set* link between h_1 and h_3 results in $\forall x_0\ \mathit{student}(x_0)$. As the *scope*s are undecided in the example, the final logic form of the sentence can have several different interpretations, including $(\forall \mathrm{x}_0 2\mathrm{x}_1 \exists \mathrm{x}_2)(\exists \mathrm{e}_0\ \mathrm{student}(\mathrm{x}_0) \wedge \mathrm{teacher}(\mathrm{x}_1) \wedge \mathrm{tell}(\mathrm{e}_0) \wedge \mathrm{story}(\mathrm{x}_2) \wedge \mathrm{arg0}(\mathrm{e}_0, \mathrm{x}_0) \wedge \mathrm{arg1}(\mathrm{e}_0, \mathrm{x}_1) \wedge \mathrm{arg2}(\mathrm{e}_0, \mathrm{x}_2))))$ and $(\forall \mathrm{x}_0 (2\mathrm{x}_1 (\exists \mathrm{x}_2 \exists \mathrm{e}_0\ \mathrm{student}(\mathrm{x}_0) \wedge \mathrm{teacher}(\mathrm{x}_1) \wedge \mathrm{tell}(\mathrm{e}_0) \wedge \mathrm{story}(\mathrm{x}_2) \wedge \mathrm{arg0}(\mathrm{e}_0, \mathrm{x}_0) \wedge \mathrm{arg1}(\mathrm{e}_0, \mathrm{x}_1) \wedge \mathrm{arg2}(\mathrm{e}_0, \mathrm{x}_2))$. If all the *scope*s are linked to the EP of "讲 (tell)", the former is the corresponding logic form.



(a) “美国华人？(American Chinese)” (b) “美国的华人？(American Chinese)” (c) “在美国的华人？(The Chinese in American)”

Fig. 4. The semantic representation for modification.

3 Case Studies

In this section, we give a set of example grammatical constructions based on different sentence types. In order to analyze a given Chinese sentence, two steps must be taken.

I. **EP Identification**. This process is analogous to the supertagging step in lexicalized grammar parsing [22].

II. **Edge Construction**. Given an EP, one needs to assign values to its arguments. The value of an EP argument is another EP. If found, we will link the two EPs, deciding the link direction accordingly.

Common semantic phenomena include modification, proposition, coordination, quantifier, anaphora and question. We give case studies to their representations, respectively.

3.1 Modification

As mentioned in the introduction, one benefit of using semantic formalism is the better handling of paraphrases. The example in Figure 2 can be expressed in our formalism in Figure 4. In all three phrases, “美国 (American)” is a modifier of “华人 (Chinese)”, indicating the location, regardless of the function words.

3.2 Proposition

Propositional words are the most essential for sentential semantics. The EP structure of a propositional word can be denoted by

$$\text{predicate:handle}(\text{arg0:x}_0, \cdots, \text{argM:x}_M), M \leq 4$$

For each $K \leq M$, argK:x_K must be in the EP structure. The arguments arg0∼arg4 refer to the core EP arguments of propositional words.

Another type of attributes for propositional words are function arguments. Different from the core arguments which are linked with content words, function arguments are defined on function words. As functional words are usually modifiers of propositional words, the edge labels between functional words and

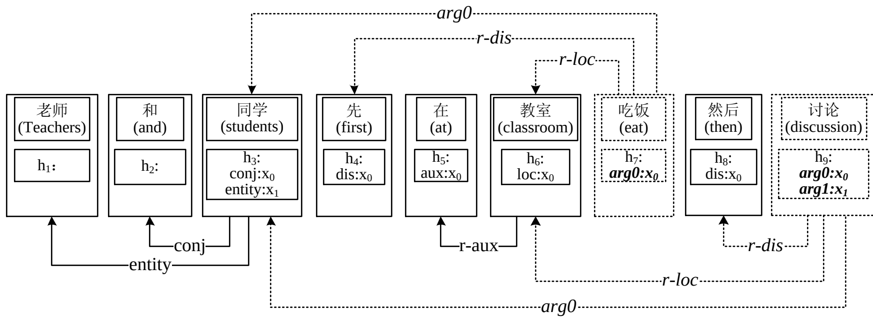


Fig. 5. The semantic representation for "老师和学生先在教室吃饭然后讨论 (Teachers and students eat in the classroom before discussion)".

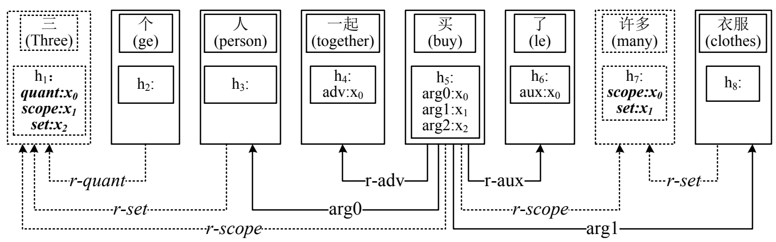


Fig. 6. The semantic representation for "三个人一起买了许多衣服 (The three persons bought many clothes together)".

propositional words start with the mark "r-" (Sec 2.3). Functional words can have multiple heads since they can modify multiple propositional words.

Figure 5 shows an example semantic representation of this case. There are two propositional words in the example: "吃饭 (eat)" and "讨论 (discuss)". The EP of the former has one argument, while that of the latter has two arguments, with the value of the second argument missing from the sentence. The function words "先 (first)" and '然后 (following)" are linked to "吃饭 (eat)" and "讨论 (discussion)", respectively, where the functional word "教室 (at classroom)" has two heads, modifying both propositional words.

3.3 Quantifier

The semantic representation of quantifier words is essential to support logic conversion.

The two essential arguments of quantifier words are *scope* and *set*. Quite often, there is a measure word following a quantifier word, and a third argument *quant* denotes this phenomenon.

Figure 6 shows an example with two quantifier words. The word "许多 (many)" has only the arguments *scope* and *set* in its EP structure, while the word "三 (three)" has three arguments in its EP due to the measure word "个

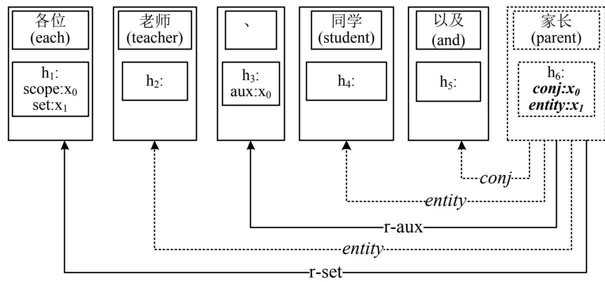


Fig. 7. The semantic representation for "各位老师、同学以及家长 (Teachers, students and parents)".

(ge)" after it. The value of argument *set* of "许多 (many)" is "衣服 (clothes)", and the same argument for "三 (three)" is "人 (person)". The argument *scope* for the both quantifier words points to "买 (buy)", which indicates that the three persons bought many clothes together (i.e. $(3x_0 \;\; nx_1)(\exists e_0 \;\; person(x_0) \wedge n > 1 \wedge clothes(x_1) \wedge buy(e_0) \wedge arg0(e_0, x_0) \wedge arg1(e_0, x_1)))$, but not separately[2].

3.4 Coordination

The coordination structure is a very important issue in the semantic representation. Most previous work builds intermediate nodes to represent its semantics. However, additional nodes can make the dependencies between words much complicated. We choose to follow syntactic dependency treebanks and add two additional arguments *conj* and *entity* for the coordination phrase structure. All entities are linked to the last entity with the label *entity*, and all conjunction words are linked to the last entity with the label *conj*.

Figure 7 shows an example coordination structure. The three words "老师 (teacher)", "同学 (student)" and "家长 (parent)" are coordinated nouns in the sentence. We apply the two more arguments *conj* and *entity* to the EP of the last word "家长 (parent)". The two remaining words are linked to the word with the label *entity*, and the conjunction word "以及 (and)" is linked to the word with the label *conj*.

3.5 Anaphora

We adopt the semantic role *refer* (referencer) to indicate the true value of a pronoun. Thus a pronoun's EP structure can be written as predicate:handle(refer:x_0). Figure 8 shows an example, where the pronoun "他 (he)"in the sentence is a reference of the proper noun "小明 (Xiaoming)".

[2] For a distributive reading the argument *scope* for "三 (three)" points to "许多 (many)" and that of "许多 (many)" points to "买 (buy)", resulting in the logic meaning $(3x_0(nx_1(\exists e_0 \;\; person(x_0) \wedge n > 1 \wedge clothes(x_1) \wedge buy(e_0) \wedge arg0(e_0, x_0) \wedge arg1(e_0, x_1))))$.

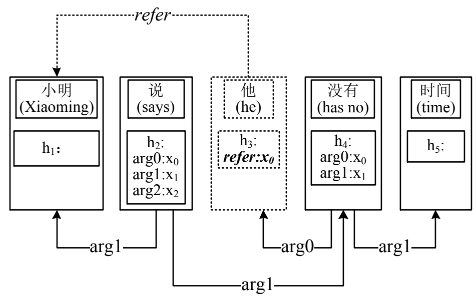


Fig. 8. The semantic representation for "小明说他没有时间 (Xiaoming said that he had no time)".

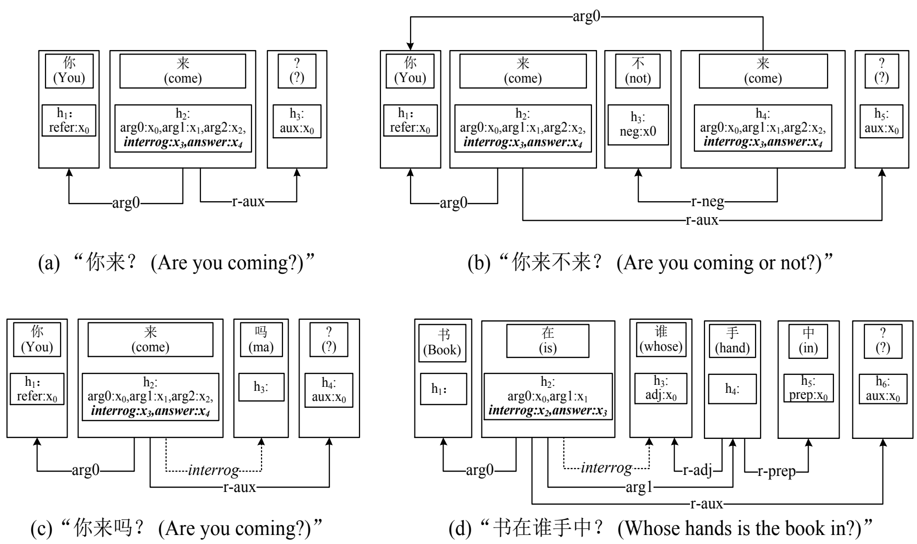


Fig. 9. Examples of semantic representation for questions.

3.6 Question

Chinese questions are generally marked by interrogative words. However, sometimes the interrogative can be omitted from a sentence. We add the two related semantic arguments *interrog* (interrogative) and *answer* to the head propositional words of the sentence.

We show four examples in Figure 9, where Figure 9(a) and 9(b) are both questions without interrogative words, and Figure 9(c) and 9(d) are both questions with interrogative words. Figure 9(a) is a question recognized by the punctuation while 9(b) matches a common question pattern. Figure 9(c) is triggered by the interrogative particle word "吗 (ma, a question tag) " while Figure 9(d) is a question triggered by the interrogative word "谁 (whose)". To treat the these conditions consistently, the semantic arguments are imposed on the propositional words in the questions. The added arguments are in the EP of "来 (come)" for the first three examples and in the EP of "在 (be in)" for the last example.

4 Related Works

One dominant approach to sentential semantics is based on the Montagovian framework [23], adopting syntactic grammars such as CCG to build logic meaning through semantics composition. In our work, we choose not to adopt this framework for Chinese semantics as it needs resolving semantic ambiguities syntactically, which is rather difficult for Chinese. The Chinese syntax is more irregular than that of English as it is a parataxis language and lacks morphology.

Underspecification [24–26] is a useful tool for semantic representation, which allows semantic construction to be independent to syntactic structures. MRS is a representative grammar using this tool [17]. The EP structure was first introduced by this formalism, and our grammar is largely inspired by it. However, we are different in several aspects. For example, we abandon the MRS's requirement of argument *scope* for every EP, treating *scope* as a normal argument to particular EPs, but allowing underspecification, because we find that in most conditions the scope is bound to another sematic argument of the EP. For another example, we build a DAG grammar formalism for sentential semantics directly, which is independent of an extra syntactic formalism. Hence our grammar can be analyzed using existing statistical parsing algorithms.

Some researchers use Propbank and syntax dependencies for semantic representation, and the Propbank annotation has been adopted for Chinese [19]. However, this representation can only express the predicate-argument structures of propositional words conveniently. Moreover, it does not support conversion into logic forms. Debusmann et al. [27] propose Extensible Dependency Grammar (XDG) to denote sentential semantics. They classify semantic phenomena into several views; each view requires a separate structure graph.

We choose to use a single graph for the semantics of a sentence. Che et al. [4] introduces a semantics oriented dependency grammar for Chinese. They exploit the same structural representation as syntactic dependency grammars. However, they introduce 123 semantic labels to substitute syntactic labels in the dependency structures.

This fine-grained label set adds to the annotation cost, as well as difficulty in statistical disambiguation. As a result, the best performing systems as reported by Che et al. [4] gave less than 62% LAS. In addition, Che et al.'s formalism does not allow logical conversion since their dependencies are built over words.

Our formalism is designed taking consideration of and drawing inspirations from all the above work and the characteristic of the Chinese language. It abandons the Montagovian framework and adopts the underspecified framework. It denotes sentential meaning using direct acyclic graphs. It suggests the use of EPs rather than words as the basic units to build semantic relations, making the representation concise.

5 Conclusion and Future Works

We discussed several challenges to Chinese semantic treebanking and proposed a possible solution based on elementary predicates and semantic links, combining the strengths of semantic frames and light-weight grammars. Compared to existing Chinese treebanks, this formalism consists of a much simpler label set, and has a direct conversion to logical forms. Future work includes the construction of a treebank in large scale.

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