Implementing Categorial Grammar in Semantic Analysis: from a Frame Semantics' View

Ke Wang
Dalian University of Technology,
116024, P.R. China
wang.coco.ke@gmail.com

Rongpei Wang
Dalian University of Technology,
116024, P.R. China
rpwang1@yahoo.com

Abstract

In this paper, we propose a new idea that semantic frames are taken as the functions, and semantic categories (usually labeled with semantic roles) are taken as arguments. Thus, a semantic frame can apply to semantic categories if semantic categories are consistent with the semantic frame. Beta-reduction is used to represent the idea of the application of semantic frame to semantic categories. Semantic consistency is tested through β-unification. It is concluded semantic consistency problems are decidable if verbs are typable in the system of frames.

1 Introduction

Grammar is the set of rules that governs the composition of phrases or words to be meaningful and interpretable in a given natural language, i.e. a grammar should explain why a sentence is acceptable while others are not. In this case, syntax and semantics are not opposite to each other. However, many of semantic issues cannot be explained in CGs[1]. For example, the following examples share the same construction, coordination-reduction, which has been finely explained in Combinatory Categorial Grammar (Mark Steedman, 1987). Both (1) and (2) are grammatical in CGs; however, (2) is completely unacceptable in semantics.

(1) Mary planted and Harry cooked the beans.

(2) *Harry cooked and Mary planted the beans.

Mostly, CGs can distinguish sentences from non-sentences, but it is inefficient when to explain this kind of semantic issues. In this paper, we tried to diagnose the above semantic problem through combining the ideas of frame semantics and logic inference methods. We propose a new idea that semantic frames are considered as functions, and semantic categories (usually labeled with semantic roles) are taken as arguments. Thus, a semantic frame can apply to semantic categories if these semantic categories are consistent with the semantic frame.

We used semantic roles to replace the syntactic categories of CGs so as to enrich it with a stronger capability in semantic analysis. Then, the combinator C (Haskell Curry, 1942) is introduced, with which the disturbed positions of arguments in a complex sentence could be reordered. After that, beta-reduction was used to represent the idea of the application of semantic frame to semantic categories. In seeking of a method to resolve this problem, it is proposed that the unification of typed feature structures that represent the semantic categories and semantic frames is right the one we are pursuing. However, it is still quite difficult to decide whether an instance of unification could have a solution in lambda calculus. Finally, β-unification (A.J. Kfoury, 1999) is discussed, which says that an instance of unification problems in lambda calculus can have a solution if and only if lambda term M (from which the instance is transformed), is strongly β-normalizable. M is strongly β-normalizable if and only if M is typable in the lean fragment of the system of intersection types. Thus, it was hypothesized that the semantic frame system is the lean fragment of the system of intersection types

[1] CGs is the general name of variants of Categorial Grammar. A better introduction of variants of CG can be found in Mary M. Wood's work (1995).

and verbs are typable in such lean fragment of the system. It is concluded that semantic consistency problems are decidable if verbs are typable in the system of frames.

2 Methods used in this paper

2.1 Syntactic Analysis in Categorial Grammar

The Categorial Grammar originates from the ideas in work of Ajdukiewicz (Kazimierz Ajdukiewicz, 1935) and Bar-Hillel (Yehoshua Bar-Hillel, 1953) (hence AB-Categorial Grammar). Joachim Lambek (1958) introduced a syntactic calculus along with various rules for the combination of functions, which mainly include Application, Associativity, Composition, and Raising. CGs is distinguished from other formal grammars by its syntactic categories and inference rules. The syntactic categories **SyC** is defined as follows:

Atomic categories: NP, S, …∈**SyC**
Complex categories: if X, Y∈**SyC**, then X/Y, X\Y∈**SyC**.

Complex categories X/Y or X\Y are functors with an argument Y and a result X. For instance, NP/NP would be the type of determiner that it looks forward for a noun to produce a noun phrase; S\S would be the type of adverb that it looks backward for sentence to produce a sentence, as illustrated in (4) and (5):

(3) He sells tomatoes.
NP S\NP/NP NP
_______S\NP_____
_______S________

(4) I bought a red book yesterday.
NP S/NP\NP NP S\S
_____S/NP____
_______S_____
________S________

Application and Composition are the most frequently used rules in CGs. “the rule of forward application states that if a constituent with category X/Y is immediately followed by a constituent with category Y, they can be combined to form a constituent with category X. Analogously, backward application allows a constituent X\Y that is immediately preceded by a constituent with category Y to combine with this to form a new constituent of category X” (Julia Hockenmaier and Mark Steedman, 2005).

- Forward application
  X/Y Y → X
- Backward application
  X\Y Y → X

“Composition allows two functor categories to combine into another functor” (ibid).

- Forward composition
  X/Y Y/Z → X/Z
- Backward composition
  Y\Z X\Y → X\Z

For example, in (5), the article “a” asks for a noun phrase to be its argument, so does the adjective “red”; therefore they are composed together.

(5) a red book
NP/NP NP/NP NP
____NP/NP___
_______NP_____

Some more sophisticated examples could be found in Mark Steedman’s work (2000).

2.2 Semantic Representation in Frame Semantics

Frame semantics is the development of C. Fillmore’s case grammar (Fillmore, 1968). The basic idea is that one cannot understand meaning without world knowledge. A semantic frame is defined as a structure describing the relationships among concepts evoked by words (mostly, by verbs). For example, in an exchange frame, the concepts of Seller, Buyer, and Goods can be evoked by words, e.g. *sell*, *buy*, etc. In a sentence, semantic structures that are composed of these concepts are usually represented by the syntactic relations of semantic roles over predicates, as the followings:

(6) He sells tomatoes.
Seller <exchange> Goods

(7) I bought a red book yesterday.
Buyer <exchange> Goods Time

The assignment of semantic roles depends on the meanings of predicate, and on the properties of the constituents. For example, in

(8), “tomatoes” is assigned Patient, instead of Goods; because, the predicate “cooked” evoked frame <cook> and all the concepts related to <cook>, i.e. Agent and Patient. In (9), “tomatoes” is assigned Theme, because its state does not change after it is moved to “truck”.

(8) He cooked tomatoes.
Agent <cook> Patient

(9) He loaded truck with tomatoes.
Agent <fill> Goal Theme

The main difference between Patient and Theme is that Patient undergoes the action and its state changes, whereas Theme does not change.

2.3 Using CGs’ rules for Semantic Analysis

In this paper, we presented our different view on application and composition, that composition rule should be only used to combine clausal sentences into complex sentences. We did not intend to claim that semantic analysis is independent from syntactic analysis; instead, we propose semantic analysis should be considered as a complement to syntactic analysis; both are equally important in a grammar.

It is supposed that mostly, verbs bear the meaning of semantic frames. Thus, the predicates in (3) and (6) can be ***rewritten*** as (10). It means frame <exchange> has two arguments, namely, Seller, and Goods:

(10) Exchange frame:
<exchange>\Seller/Goods

Through the application rules, we can extract semantic frame from (4), as shown in (11):

(11) He sells tomatoes.
Seller <exchange>\Seller/Goods Goods
_______<exchange>\Seller______
_______<exchange>__________

Semantic frames can also be composed into a complex frame, such as:

(12) John said [he sold tomatoes]^{Content}
Informer X Seller Y Goods
X’ Y’

Here, we replace the verb’s meaning with X and Y. Intuitively, Y is lower than X in that it is the predicate of X’s complement. X’ represents the semantic frame of main clause, and Y’ represents the semantic frame of the complement (in the followings of this paper, we will continue using X and Y to represent the predicate verbs of the main clause and secondary clause respectively, and X’ and Y’ to represent semantic frames). Thus,

- X’=X\Informer/Content
- Y’=Y\Seller/Goods

The two semantic frames are ***compose****d* in the way of (13):

(13) X’/Y’ Y’ → X’

Where, X’/Y’ means, the semantic frame X’ asks for Y’ to be its argument. We write it in a more conventional form, *X’(Y’)*. Note that X’ is the lexical meaning of verb ‘said’, and that the composition of two semantic frames into complex frame needs to ***convert*** each semantic frame into a more complex form according to their surrounding features. Recall, article ‘a’ is tagged with ‘NP/NP’ in (5), which means it must be immediately followed by a noun phrase.

3 Examples

3.1 Insertion

In Bar-Hillel’s (1953) paper, there is a tough problem that CGs cannot overlook, as shown in (14):

(14) Paul, strangely enough, refuses to talk.
Z X Y

Literally, it means “*it is strangely enough that Paul refuses to talk*”. Apparently, (14) is a complex construction composed of two semantic frames. We just need to make them go back to their places.

In Curry’s work (1942), he presented a combinator C, which is used for switching the first two arguments of a function. Here, we use it to ***reorder*** the disturbed arguments’ position. Example (14) can be converted into (15) without causing any change of meanings.

(15) Strangely enough, Paul refuses to talk.

reorder:	X	Z	Y
rewrite:	X' (X'=X)		Y'(Y'=Y\Z)
convert:	X'/Y'		Y'
compose:	X'/Y'	Y' → X'	

where, *rewrite*, *convert*, and *compose* are the operators that have been introduced in section 2. (16) and (17) are similar examples, if we consider 'must' in (17) as a disjunct, for example 'I guess', rather than a modal verb:

(16) He, *frankly speaking*, is not good enough.

(17) He *must* be angry.

3.2 Coordination-reduction

The examples (1) and (2) mentioned at the beginning of this paper share the same construction, coordination-reduction. The omitted constituents did not disappear; actually they exist in deep semantic layers, as shown in the followings:

(1)'Mary planted […]^{Theme} and Harry cooked [the beans]^{Patient}.

(2)'* Harry cooked […]^{Patient} and Mary planted [the beans]^{Theme}.

To give a further explanation on why (2) is not acceptable in semantics, we should use world knowledge. We may share the common sense that an action of change cannot be withdrawn by human power. In logics, this kind of world knowledge can be represented as the application of semantic frames (functions) to semantic roles (variables), as shown in (18) and (19):

(18) Mary planted and Harry cooked the beans.

	Y	X
	Harry cooked the beans	Mary planted […].
reorder:	X	Y
rewrite:	X'	Y'
convert:	X'/Y'	Y'/[…]^{Theme}
compose:	X'/Y' Y'/[…]^{Theme}	→X'/[…]^{Theme}

(X'= X\Cook/Patient; Y'=Y\Agent/Theme)

(19) λPatient. X'[Patient:=Theme]

Note that the composition of semantic frames can be realized either by application rules or composition rules. In (18), X'/[…]^{Theme} means semantic frame X' applies to […]^{Theme}. As shown in (19), if […]^{Theme} is consistent with X', then, it can replace the variable Patient in X'. Technically, this replacement could be implemented through the unification of semantic frame and semantic categories. It is expected to find a way, such as the one in figure 1, through which the semantic consistency of […]^{Theme} can be tested.

$$\begin{bmatrix} \mathit{variable} & \\ \text{lexical:} & [\ldots]^{\text{Theme}} \\ \text{semantic:} & [\text{Patient:animate}] \end{bmatrix}$$

Unifies with

$$\begin{bmatrix} \mathit{frame} & <\mathit{cook}> \\ \text{lexical:} & \text{cook} \\ \text{semantic:} & \begin{bmatrix} \text{Agent:} & \text{intelligent} \\ \text{Patient:} & \text{animate/inanimate} \end{bmatrix} \end{bmatrix}$$

Figure 1. The unification of […]^{Theme} and frame X' in example (19).

In figure 1, the meanings of […]^{Theme} and the frame X' are represented by a particular notation called typed feature structures. When the variable unifies with the frame, the semantic consistency is tested through the compatibility of the two structures. As it is shown, […]^{Theme} is compatible with requirements of frame <cook>. Analogously, in figure 2, […]^{Patient} is not compatible with the requirements of frame <plant>. This explains why (1) is acceptable in semantics, while (2) is not.

$$\begin{bmatrix} \mathit{variable} & \\ \text{lexical:} & [\ldots]^{\text{Patient}} \\ \text{semantic:} & [\text{Theme:inanimate}] \end{bmatrix}$$

Unifies with

$$\begin{bmatrix} \mathit{frame} & <\mathit{plant}> \\ \text{lexical:} & \text{plant} \\ \text{semantic:} & \begin{bmatrix} \text{Agent:} & \text{intelligent} \\ \text{Theme:} & \text{animate} \end{bmatrix} \end{bmatrix}$$

Figure 2. The unification of […]^{Patient} and frame <plant> in example (2)'.

The decidability of the unification is discussed in section 4. For more information about unification of typed feature structures, please refer to Carpenter (1992) and Gerald (2000)

4. Discussion

In Kfoury's work (1996), he proved that an instance Δ of unification problem U (β-unification) has a solution iff M is β-strongly normalizable, (where M is a lambda term, from which Δ can be transformed); and that M is β-strongly normalizable iff M is typable in the lean fragment of the system of intersection types.

Apart from the precise definitions and proofs, intuitively, if semantic frame were the lean fragment of the system of intersection types, and if verbs that bear the meanings of semantic frames could be typable in such system, then the semantic consistency in (19) is decidable.

Linguistically, being typable in the system of semantic frame means verbs, such as 'cook' and 'plant' in (1) and (2), are of completely different types. Therefore, verb types can explain why the semantic changes of 'the beans' caused by 'cook' is unacceptable in the semantic frame represented by verb 'plant'.

5. Conclusion

In this paper, a new idea is proposed, that semantic frames are seen as the functions, and semantic categories (usually labeled with semantic roles) are taken as the arguments of functions. Thus, a semantic frame can apply to arguments, the variables. Many complex constructions, such as insertion and co-ordination reduction can be well explained with this set of approaches.

The combinator C is used for reordering the disturbed positions of arguments in a complex sentence. Beta-reduction is used to represent the idea of the application of semantic frame to semantic categories. The idea of the proof of decidability of unification problems in β-reduction is borrowed from Kfoury's work (1999). It is concluded semantic consistency problems are decidable if verbs are typable in the system of semantic frames.

The ultimate goal of computational linguistics is to let machines understand human's language. It is hoped that the idea proposed in this paper could help to implement a real NLU system, suppose, if there were some resources that finely describe types of verbs and lexical meanings of each word of a language. Actually, there already have been some (such as, WordNet, VerbNet, and FrameNet).

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