Semantic Aspects of Minimalist Grammars *
Extended Abstract

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Abstract

Minimalist grammars are a rich lexicalized syntactic formalism which inherits the depth and wide covering of the generative tradition. Nevertheless up to now there is no straightforward way to extract the predicative structure of a sentence from syntactic analyses and from the predicative structure of the lexical items. In this paper we try to apply to this richer syntactic model the traditional correspondence between categorial grammars and Montague semantics. A similar correspondence between syntax and semantics is obtained via a description of minimalist grammars as a deductive system.

Keywords: Computational Linguistics; Natural Language Syntax and Semantics, Formal Grammars, Deductive Systems

1 The syntax/semantics interface

Possibly the most central question in linguistics is the relation between sound and meaning.

Although the question is already present in de Saussure (1981), little can be said at the *signe* level since the relation between the *signifiant* and the *signifié* of the linguistic sign is arbitrary. Nevertheless, there is, prior to the official begining of linguistics, a long tradition of relating logic and grammar which has been studied since the Ancient Greek and Latin philosophers and grammarians (see e.g. Baratin and Desbordes (1981)). Later on, Arnauld and Lancelot (1660), in their *Grammaire de Port-Royal*, clearly depicts a sentence as a complex logical structure. The rôle of syntax is crucial since it is the part of linguistics which combine the phrases in order to provide the sentence the intended meaning, i.e. tell us who does what.

Nowadays the development of generative grammar, analytic philosophy, and computational linguistics, provide tools to address this traditional question. Our work focuses on the interface between the syntactic structure and the predicative structure, at the sentence level. As a short hand for "predicative structure" we may use the word "semantics", but in this paper this term does not mean more than "predicative structure": for instance we do not consider the relation between the various predicates introduced by the lexical items which is known as lexical semantics (for instance there are some connections between "book(x)", "print(u,x)", "read(v,x)"). It does not mean that there is no connection between predicative semantics and lexical semantics, since both aspects participate to the construction of the meaning, but combining them is rather complicated, see e.g. the attempt of Pustejovsky (1995).

Concerning the predicative structure of a sentence, we refer firstly to Richard Montague (Thomason, 1974) which belongs to the logical tradition of philosophy of language: semantics is assumed to be compositional (the meaning of a compound expression is obtained from the

*This contains joint work with Maxime Amblard (Université Bordeaux 1) and Alain Lecomte (Université Grenoble 2). Minimalist grammars are due to Edward Stabler (University of California at Los Angeles).

†http://www.labri.fr/Recherche/LLA/signes/

meaning of the parts) and truthconditional (the meaning of a sentence is identified with the set of situations which make the sentence true). It should be observed however that these two requirements on semantics are independent, and one can agree on the compositional nature of semantics without reducing the semantics of a sentence to its truth conditions, as argued by Jackendoff (1995), and we shall leave out the models of the logical formulae that we obtain as semantic representation. The compositionality of semantics which is depicted by using lambda calculus put forward categorial grammar as syntactic formalism. Although Montague rather makes use of context free grammars for syntax, he also makes use of categorial grammars as an intermediate level, and the development of categorial grammars substantially developed this correspondence, trying to enrich categorial grammars without losing the correspondence with semantics, see e.g. (Moortgat, 1996). Some similar work has been done in the generative grammar, and is, according to Chomsky part of syntax. This work is closer to natural language, is not so concerned with logic (models, intentionality,...), and focuses on syntactic phenomena like possible coreference of pronouns, quantifier scope etc. see e.g. (Heim and Kratzer, 1997).

According to the minimalist program of Chomsky (1995) sentences are derived from a selection of lexical items which are syntactically combined and organized to produce a logical form (LF) and a phonological form (PF). The production of sentences is clearly described as a computational phenomenon, and these linguistic computations are shown to be very specific among other automated tasks performed by human beings.

This computational process has been described by Stabler (1997) as tree grammars, which produce the phonological form of the sentence (the sequence of uttered words) and a logical form which consists in the sequence of semantic features which describe, for instance, the correct ordering of quantifiers. Although these grammars are rich enough to describe complicated syntactic phenomena, and are computationally efficient, we do believe that the logical form obtained lacks some structure, and we believe it should be some kind of logical formula.

Because of some similarity between minimalist grammars and categorial grammars, which are both defined in terms of linguistic resource consumption, we try to encode minimalist grammars as a special kind of deductive system, in order to extend the correspondence between syntax and semantics for categorial grammar to this richer formalism.

2 Minimalist grammars

In order to provide a computational model of the minimalist program of Chomsky (1995) minimalist grammars were defined by Stabler (1997, 1999) as tree grammars. These grammars are lexicalized, that is to say a lexicon maps words into list of features. These features are of two kinds: categories (denoting kind of phrases), and functional categories (ruling movements), phonetic features and semantic features. Categorial and functional features may appear positively or negatively: a negative categorial feature in a phrase p is a demand of a phrase p' with the corresponding positive categorial feature (merge), and a place in a phrase p with a positive functional feature attracts a subphrase of p with the corresponding negative category (move).

The structure building operations are uniform and do not depend on the language, and they are defined on binary trees. A leaf of such a tree contains a sequence of features, and the internal nodes indicate in which of the the two subtrees the head is to be found, so every tree or subtree has a head, and every leaf is the head of a subtree, possibly reduced to the leaf itself.

One operation is merge which consists in combining two trees depicting phrases into a single tree, and the other one is move, which consists in moving a subtree (a phrase) to the head leaf. Both operation are triggered by the need to cancel formal features: a tree with on its head a negative categorial feature needs to consume a tree with the corresponding positive categorial feature on its head, and this triggers *merge*. Similarly a tree may have a head with a positive functional feature: it is the place which attracts a subtree whose head lacks this functional feature, that is a subtree whose head contains the corresponding negative functional feature, and this triggers *move*. Depending on the strength (weak or strong) of the functional feature, *move* can attract the whole subtree or only its semantic part.

Sentences are trees whose head is c (complementizer, i.e. sentence), and which only contain (apart from this c) interpretable features, either phonetic or semantic. The phonetic form of the sentence is the reading, from left to right of the phonetic features, and the semantic form is the reading from left to right of the semantic features.

This formalism inherits from the generative tradition a wide cover of various syntactic constructions, and moreover allows for a multilingual description of syntax. For example the shift from *Subject Verb Object* languages to *Subject Object Verb* languages correspond simply to a change in the strength of the case feature provided by the verb to its object.

Languages generated by these grammar correspond to the ones defined by Multi-Component Tree Adjoining Grammars or to Multiple Context-Free Grammars as shown by Harkema (2001); Michaelis (2001), and can be analyzed in polynomial time.

Although the semantic form give some hint on the semantic structure of the sentence, like quantifier scope, we do believe it needs to be more structured to provide the predicative structure of the sentence.

3 Categorial grammar and Montague semantics

Categorial grammars somehow have opposite properties. The parsing of Lambek grammars is NP-complete as shown by Pentus (2003), and furthermore they are many syntactic phenomena that they cannot handle... Nervertheless there is an easy correspondence between categorial analyses of sentences and their predicative structures.

Categorial grammars were introduced by Bar-Hillel (1953) and presented as a logical calculus by Lambek (1958). As minimalist grammars, Lambek grammars are lexicalized grammars: a lexicon Lex maps words into finite sets of logical formulae, and a sequence of words $w_1, \ldots, w_n$ is a phrase of type X whenever:

$$\forall i \exists t_i \in \mathrm{Lex}(w_i) \quad t_1, \ldots t_n \vdash X$$

The formulae are defined from a set of propositional variables P, usually $\{S, n, np\}$ for Sentence, $n$oun, $n$oun $p$hrase, as follows:

$$F ::= P \;\Big|\; F \setminus F \;\Big|\; F \,/\, F \;\Big|\; F \bullet F$$

The deduction relation is a restriction from intuitionistic logic, which does neither allow for duplication or erasing, nor for permuting the hypotheses. Thus a phrase a of type $X \,/\, Y$ (resp. $Y \setminus X$) requires some phrase b of type Y on its right (resp. on its left) to produce a phrase ab of type X.

The main advantage of categorial grammars is that they allow for a rule-to-rule correspondence between syntax and semantics, see e.g. (Gamut, 1991; Retoré, 2000).

It is well-known that first order logic can be described by simply typed lambda terms with two base types: e for entities and t for truth values, with constants for predicates and functions, and logical constants for logical operations: binary connectives have type $t \longrightarrow (t \longrightarrow t)$ and quantifiers over entities have type $(e \longrightarrow t) \longrightarrow t$.

Thus, the base categories have natural semantic counterparts:

(Syntactic type)*	=	Semantic type	
S^*	=	t	a sentence is a proposition
np^*	=	e	a noun phrase is an entity
n^*	=	$e \rightarrow t$	a noun is a subset of the set of entities
$(a \setminus b)^* = (b \,/\, a)^*$	=	$a^* \rightarrow b^*$	extends $(\_)^*$ to all syntactic types

If one applies this morphism to a syntactic analysis, that is a proof in the Lambek calculus of S, one obtains a proof in intuitionistic logic that is a lambda term of type t, with free variables $x_1, \ldots, x_n$ of types $t_1^*, \ldots t_n^*$. If these variables are replaced with lambda terms depicting the predicative structure of the words, then by beta-reduction one obtains a normal lambda term of type t which describes the first order formula corresponding to the sentence. Intuitively the beta reduction performs the correct substitutions and provides the predicates included in the words with their correct arguments, simply by following the syntactic structure expressed as a proof in the Lambek calculus.

4 Minimalist grammars as deductive systems

It has been noticed that the minimalist grammars of Edward Stabler share some ideas and mechanisms with categorial grammars Lecomte (1999, 2000, 2001, 2003); Cornell (1999); Vermaat (1999, 2003), or, more generally, resource logics (Retoré and Stabler, 2003). Both grammatical formalisms are lexicalized, and both the categorial formula and the minimalist sequence of features describe the consumption of linguistic resources by words and phrases.

Thus, Lecomte and Retoré (1999a,b, 2001, 2002, 2003) defined minimalist grammars as a deductive system which allows to combine the advantages of minimalist grammars:

- a covering of sophisticated syntactic phenomena
- a multilingual perspective
- a polynomial parsing

with the advantage of categorial grammars:

- their easy interface with predicative semantics
- the existence of learning algorithms

The *merge* operation clearly looks like the residuation or modus ponens of categorial grammars, and causes no trouble. In order to describe *move*, one needs to relates two positions in the phrase. Therefore the deductive system we used is partially commutative logic introduced by de Groote (1996), or intuitionistic non commutative logic (Abrusci and Ruet, 1999), that is Lambek calculus enriched with commutative connectives: indeed the elimination rule of the commutative product cancel two hypotheses located at two distinct and not necessarily contiguous places. We interpret this as a movement from the rightward place to the leftward place.

In this grammars we only make use of elimination rules, and thus the complexity of proof search that is parsing should be much better than general proof search in resource sensitive logic, which is usually an NP complete problem.

5 Computing semantic representations

Consequently minimalist grammars are viewed as a kind of categorial grammar, with a deductive mechanism as generative rules, and we can hope to extend the relation between syntactic analyses and predicative structure that is familiar for categorial grammars..

As shown by Amblard (2003), several difficulties arise, if one wants to perform a rule-to-rule correspondence between syntactic rule and predicate construction.

- Firstly we need to enrich the simply typed lambda calculus with product types since we use products in the syntax, but this is common and harmless.
- Secondly the functional categories have an unclear semantics: although case as a meaning (nominative, accusative etc. have to do with the rôle played by the determiner phrase) it has no clear logical counterpart as a type. So we provide such functional categories with a type variable which unifies in order to avoid type mismatch.
- Finally, these minimalist derivations introduce variables whose only purpose is to be discharged in a product rule with another variable or term, and these are different from the hypotheses corresponding to words. Thus, instead of always using closed lambda terms, these variables are treated as terms with a context of free variables that which are abstracted before they are discharged in product elimination rules, and this avoids type mismatch.

6 Prospects

Consequently we have an algorithm for extracting semantic representation from minimalist analyses, but is not as elegant as the one for categorial grammar. it exhibits some pleasant connection between movement (syntax) and type raising (viewing determiner phrase or noun phrases as generalized quantifiers). Improvement and simplification could arrive from a logical understanding of functional categories, from different coding of minimalist grammar into deductive systems, using lambda abstraction (i.e. implication introduction) to depict movement: we are presently working on this later point.

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