

Lexical-Functional Grammar and Order-Free Semantic Composition

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This paper summarizes the extension of the theory of lexical-functional grammar to include a formal, model-theoretic, semantics. The algorithmic specification of the semantic interpretation procedures is order-free which distinguishes the system from other theories providing model-theoretic interpretation for natural language. Attention is focused on the computational advantages of a semantic interpretation system that takes as its input functional structures as opposed to syntactic surface-structures.

A pressing problem for computational linguistics is the development of linguistic theories which are supported by strong independent linguistic argumentation, and which can, simultaneously, serve as a basis for efficient implementations in language processing systems. Linguistic theories with these properties make it possible for computational implementations to build directly on the work of linguists both in the area of grammar-writing, and in the area of theory development (cf. universal conditions on anaphoric binding, filler-gap dependencies etc.).

Lexical-functional grammar (LFG) is a linguistic theory which has been developed with equal attention being paid to theoretical linguistic and computational processing considerations (Kaplan & Bresnan 1981). The linguistic theory has ample and broad motivation (vide the papers in Bresnan 1982), and it is transparently implementable as a syntactic parsing system (Kaplan & Halvorsen forthcoming). LFG takes grammatical relations to be of primary importance (as opposed to the transformational theory where grammatical functions play a subsidiary role). Sentences are derived by means of a set of context-free phrase-structure rules annotated with functional-schemata. There are no transformational rules. The pivotal elements in the theory are the phrase-structure rules, and in particular, the lexical rules. A typical LFG-analysis is the treatment of the passive-construction implied by the rules and lexical entries in (1a-c).

(1)a. Phrase-structure rules (annotated with schemata determining the assignment of grammatical relations):

S --> NP VP
 (↑ SUBJ)=↓ ↑=↓
 VP --> V NP NP PP*
 ↑=↓ (↑ OBJ)=↓ (↑ OBJ2)=↓ (↑ OBL_θ)=↓
 (↑ PCASE)= OBL_θ
 VP
 (↑ VCOMP)=↓
 PP --> P NP
 (↑=↓) (↑=↓)

b. Lexical Rule of Passive:

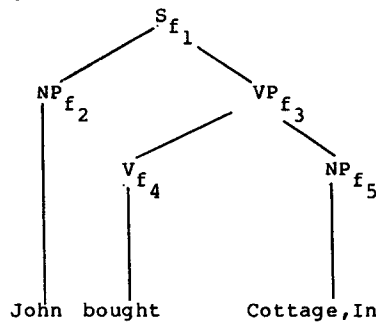
OBJ --> SUBJ
 SUBJ --> OBL_{BY}
 Optionally: OBL_{BY} -->

c. Lexical entries (derived by the lexical rules):

(i) buy V (PRED)='buy<(↑ SUBJ)(↑ OBJ)>'
 (ii) buy V (PRED)='buy<∅, (↑ SUBJ)>'
 (iii) buy V (PRED)='buy<(↑ OBL_{BY})(↑ SUBJ)>'

(2)a. John bought Cottage, Inc.

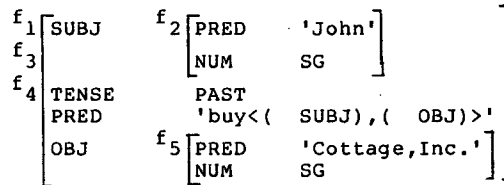
b.



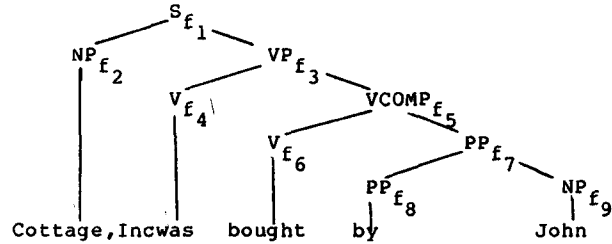
c. Functional equations

(f₁ SUBJ)=f₂
 (f₂ PRED)='John'
 (f₂ NUM)=SG
 f₁=f₃
 f₃=f₄
 (f₄ PRED)='buy<(↑ SUBJ), (↑ OBJ)>'
 (f₃ OBJ)=f₅
 (f₅ PRED)='Cottage, Inc.'
 (f₅ NUM)=SG

d. Functional Structure (acyclic-graph)



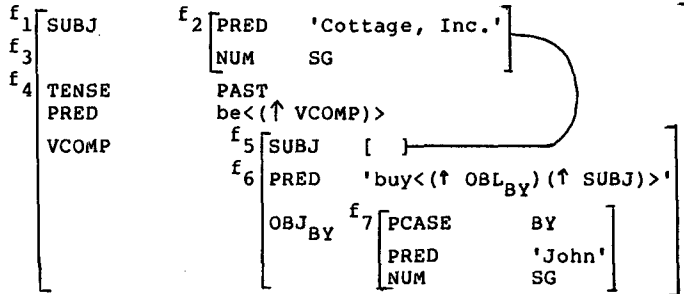
(3) a. Cottage, Inc. was bought by John
 b.



c. Functional Equations

- $(f_1 \text{ SUBJ}) = f_2$
- $f_1 = f_3$
- $f_3 = f_4$
- $(f_4 \text{ PRED}) = \text{'be} < (\uparrow \text{VCOMP}) > \text{'}$
- $(f_3 \text{ VCOMP}) = f_5$
- $(f_5 \text{ SUBJ}) = f_2$
- $f_6 = f_5$
- $(f_6 \text{ PRED}) = \text{'buy} < (\uparrow \text{OBL}_{\text{BY}}), (\uparrow \text{SUBJ}) > \text{'}$
- $(f_5 \text{ OBL}_{\text{BY}}) = f_7$
- $f_7 = f_8$
- $f_7 = f_9$
- $(f_7 \text{ PCASE}) = \text{OBL}_{\text{BY}}$
- $(f_9 \text{ PRED}) = \text{'John'}$
- $(f_9 \text{ NUM}) = \text{SG}$

d. Functional Structure



The phrase-structure rules in (1 a) generates the phrase-structure tree in (2 b). Each phrase-structure tree is indexed. The indices instantiate the up- and down-arrows in the functional schemata which are found in the phrase structure rules. An up-arrow refers to the node dominating the node the schemata is attached to. A down-arrow refers to the node which carries the functional schemata. The result of the instantiation process is the set of functional equations in (2 c). These equations describe the functional structure (f-structure) in (2 d).

The functional structures provide, in canonical form, a representation of the meaningful grammatical relations in the sentence. The functional equations, mediate between the constituent-structure and the functional-structure. Each functional equation determines an aspect of the functional-structure. When the functional equations are solved

they uniquely determine the functional-structure. Moreover, the order in which the equations are processed is immaterial for the final result (see Kaplan and Bresnan 1981). The derivation of functional-structures is order-free. The semantic theory which accompanies the theory of functional structures provides, in its turn, an order-free derivation of semantic representations from functional structures.

The theoretical problem of natural language interpretation can be decomposed into three tasks: (1) Unraveling all possible thematic relations holding in a sentence; (2) Composition of the meaning of the constituents of the sentence into a well-defined and coherent representation of the meaning of the entire sentence; (3) Specifying all possible scope and control-relations holding in a sentence.

The unraveling of the thematic relations in a sentence is already accomplished in f-structure; no special moves are therefore needed in the semantics to establish the propositional equivalence of active-passive pairs or pairs with and without Raising, Equi etc.. Notice that both the f-structure for the active sentence, (2d), and the f-structure for the passive sentence, (3d), contain a f-structure with the predicate 'buy<.....>', and the arguments John and Cottage, Inc. are tied to the same argument positions in this predicate in the active sentence as well as in the passive sentence, thus expressing the truth-conditional equivalence of the two utterances.

The task of semantic composition and the determination of scope relations require that semantic representations be derived from the functional structures.

Rather than translating functional structures into formulas of standard predicate calculus, f-structures are mapped into acyclic graphs called semantic structures (cf. 4a). Since semantic structures are acyclic graphs, just like functional structures, symmetric constraining equations (cf. 2b and 3b) can be used to define an order-free derivation of semantic structures from functional structures just as functional equations yield an order-free derivation of f-structures from annotated phrase-structure trees. Each constraining equation in the mapping from f-structure to semantic structure adds information about the semantic structure of a sentence. Specifically if an f-structure, f has a PRED whose value is the semantic form α , then the equation (M_f PREDICATE) = α is introduced, which tells us that the semantic structure corresponding to f , M_f , has a PREDICATE attribute whose value is the translation in intensional logic of α . Each constraining equation adds a bit of information about the semantic structure, and just as in a jigsaw-puzzle what piece is found at what time is of no consequence for the final outcome.

It is the functional structure which drives the semantic composition, not the application of specific syntactic rules. This makes it possible to construct a highly constrained, and universal, theory of semantic composition: there are only a small number of structurally distinct configurations in f-structure (the predicate-, argument-, quantifier-, control-, and adjunct-relations). Explicit semantic composition rules for each of these configurations have been constructed. This enables the interpretation of any well-formed f-structure. Once the semantic composition rules for functional structures have been correctly

stated they will extend to cover any sentence, which is assigned an f-structure by the grammar. The composition rules do not have to be revised as the coverage of the grammar is extended, or as new languages are described. The semantics for the LFG-theory is clearly more easily transportable than the semantics of systems where each syntactic rule requires a special semantic rule (Bach 1976).

The semantic translation rules, working off of the f-structures in (2d) and (3d) give rise to constraining equations that determine the semantic structure in (4a) as the semantic representation for both John bought Cottage, Inc. and Cottage, Inc. was bought by John. The semantic structure corresponds to the formula of intensional logic in (4b).

(4) a.

PREDICATE	buy'
ARG1	$\lambda PP(j)$
ARG2	$\lambda PP(c)$

b. $buy_*(j,c)$

In the semantic structure the translations of the basic meaningful expressions of the sentence are present. There is no reflex of syntactic expressions without independent meaning (expletives, it, there, governed prepositions, by, etc.). The values of the attribute PREDICATE are semantic functions, and the functional arguments are identified by the the attribute ARGi. Semantic composition consists of the application of the functions to the intensions of the meanings of the functional arguments.

The scope of NP's with quantifier phrases is explicitly indicated in semantic structure, as are all occurrences of semantic arguments which the quantifiers bind. The semantic reflex of functional control is also explicated in semantic structure.

The construction of meaning representations from f-structures proceeds by successive approximation from any point in the sentence by way of the symmetrical constraining equations. The algorithmic specification of the interpretation process does, therefore, not impose any arbitrary constraints on the order in which the semantic composition of the words should proceed. Instead, one is free to impose such constraints on the order of steps in the interpretation procedure as proves to be psychologically and/or computationally motivated. The use of symmetric constraining equations and the resulting monotonic character of the mapping between f-structures and meaning representations is also useful in clearing the way for interpretation of sentence fragments. As it stands, the procedure can, if desired, proceed from left to right in a string of words, as they are being presented. The composition of sentence meanings within the Montague Semantics framework, in contrast, typically proceed from the most deeply embedded constituent and outward (see Thomason 1976, Dowty et al 1981). Interleaving of syntactic and semantic processing is also facilitated when there are no unmotivated constraints on the order of steps in the semantic processing of the sentence. Within this approach to semantic interpretation it is also possible to let the order of steps in the parsing of a sentence be determined by efficiency considerations, which may vary from sentence to sentence and even from phrase to phrase within a given sentence. An imposition of order in the abstract specification of the composition process would limit implementation choices prematurely.

In addition to the processing advantages, the semantic theory for lexical-functional grammars also offers significant simplifications in the analysis of a number of controversial and/or recalcitrant constructions such as Raising-, There-insertion, Passive, and constructions with dismantled idioms. This is an illustration of the efforts to search for evidence for the theory both in linguistic arguments and through computational efficiency considerations.

References

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