

25. Lexical-Functional Grammar

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Abstract

LFG is a constraint-based theory with the goal of combining linguistic insight with computational tractability and implementability. As LFG separates surface form from functional dependency, restrictive assumptions about configurationality dominate analyses. LFG has been used to analyze diverse phenomena, including discontinuous constituents and long-distance dependencies in a large number of typologically diverse languages. As a result, a broad range of theoretical, descriptive and computational linguists work within LFG.

1. Introduction

Lexical-Functional Grammar (LFG) took shape in the late 1970s when Joan Bresnan's linguistic concerns about the continued viability of Transformational Grammar met up with Ron Kaplan's ideas about psycholinguistics and computational modelling. The collection of papers in Bresnan (1982b) sets out the fundamental ideas of LFG. The theory

has since been extended to include new ideas and cover more data from a wide array of languages, but the fundamental ideas put forth in the late 1970s and early 1980s continue to be valid.

LFG has the goal of combining linguistic sophistication with computational implementability (Dalrymple et al. 1995). A broad range of theoretical, descriptive and computational linguists work within LFG, with some work also being done in psycho- and neurolinguistics. Several current textbooks are available (Bresnan 2001; Dalrymple 2001; Falk 2001), as is a description of a major computational grammar development effort (Butt et al. 1999).

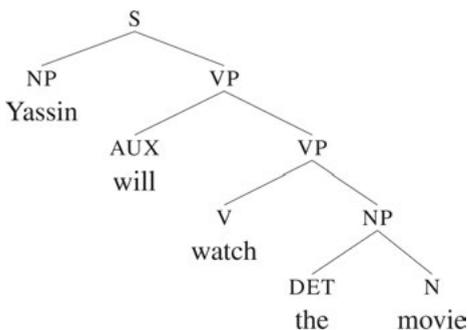
This chapter is structured as follows. Section 2 discusses the basic LFG architecture. With just this basic architecture, interesting linguistic phenomena can be dealt with simply and elegantly. This is demonstrated in section 3, where we provide sample analyses for some core syntactic phenomena. In section 4, we introduce LFG's linking theory and its application to data that have been discussed centrally within LFG. In section 5, we discuss interfaces to other modules of grammar, such as prosody, information-structure, semantics and morphology, as well as newer developments with respect to combining Optimality Theory (OT) with LFG. The chapter closes with a look at computational issues and resources in section 7.

2. LFG basics: c- and f-structure

LFG posits two distinct syntactic representations: c(onstituent)-structure which encodes surface precedence and dominance in a tree structure and f(unctional)structure which encodes grammatical relations and other syntactic features in an attribute-value matrix that is basically a dependency representation. Simplified c- and f-structures for a simple transitive sentence are shown in (1). Throughout this chapter f-structures are simplified for expository purposes. In many instantiations of LFG, all semantically relevant material such as information about telicity, definiteness or animacy is recorded in the f-structure to then become part of the semantics. See (63) for how the different levels of representation feed into the semantic meaning of a sentence.

(1) a. *Yassin will watch the movie.*

b. **c-structure**



c. **f-structure**

PRED	'watch<SUBJ,OBJ>'
SUBJ	[PRED 'Yassin'
OBJ	[PRED 'movie'
	[SPEC the]
TENSE	future

Differences in word order are reflected directly at the c-structure: sentences with different word orders may therefore correspond to identical, or extremely similar, f-structures, especially in “free” word order languages. (Languages vary as to ordering possibilities and as to how word order is connected up to information structural differences. See section 5.2 for a short discussion of proposals within LFG which integrate a representation of information-structure.) For example, the German equivalent of (1) can have (at least) the two forms in (2).

- (2) a. *Yassin wird den Film ansehen.* [German]
 Yassin will the.M.SG.ACC film.M.SG watch
 ‘Yassin will watch the movie.’
- b. *Den Film wird Yassin ansehen.* [German]
 the.M.SG.ACC film.M.SG will Yassin watch
 ‘Yassin will watch the movie.’

These will be analyzed with different c-structures, but identical f-structures except for the choice of sentence topic, cf. *Yassin* in (2a); *the movie* in (2b). Indeed, for applications involving machine translation, f-structure is considered to be the appropriate level to work with, because this level of representation abstracts away from information that is too language particular, but still contains enough syntactic information to be useful (e.g., Kaplan et al. 1989; Sadler 1993; Frank 1999; Riezler and Maxwell 2006; Graham et al. 2009).

While we have used a very simplified c-structure representation in (1), LFG does assume a version of X'-theory that goes back to Bresnan (1977) and that includes restrictions on the correspondence between different types of c-structure positions and the grammatical functions they can correspond to in the f-structure. For current assumptions about c-structural representations and constraints on c-structure, see Bresnan (2001); Asudeh and Toivonen (2009) and references therein.

F-structures are referred to as a projection from the c-structure because they are related to the c-structure via a formal system of annotations. A typical (simplified) example for a fragment of English is shown in (3). The c-structure is built up on the basis of phrase structure rewrite rules. The rule in (3a), for example, says that a sentence consists of two major constituents, an NP and a VP. In effect, the S (sentence) is rewritten as an NP and a VP. Rewrite rules are part of the common heritage of modern generative syntactic theories (cf. Chomsky 1965) and continue to be a standard part of computational linguistics. As the mathematical basis of LFG is defined in terms of model theory, rewrite rules as in (3) are formally realized as a system of constraints that are satisfied by linguistic structures; see Kaplan (1995) and Pullum and Scholz (2001) for further discussion.

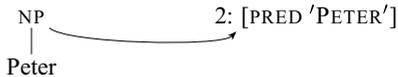
- (3) a. $S \rightarrow \text{NP VP}$
 $(\uparrow\text{SUBJ})=\downarrow \uparrow=\downarrow$
- b. $VP \rightarrow V \text{ NP}$
 $\uparrow=\downarrow (\uparrow\text{OBJ})=\downarrow$

The phrase structure rules in (3) are annotated with functional equations. These equations provide the basis for computing the f-structure (information about number, person, tense,

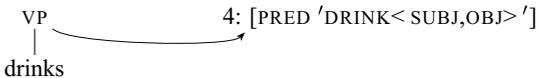
etc. is part of the lexical entries of the nouns and the verb in our example). The up arrow refers to the f-structure of the mother node, i.e., VP in (3b), the down arrow references the current node, i.e., V or NP in (3b). The annotations relate the c-structure in (1b) and the f-structure in (1c) via a formal mathematical projection φ .

Without going into too much detail, the representations in (4)–(6) show how the information provided by the annotations is projected onto the f-structure. In fact, the up and down arrows stand for variables, which have been instantiated by integers in (4)–(6). These arbitrary integers are used to label pieces of the f-structure.

$$(4) \quad (2 \text{ PRED}) = \text{'PETER'}$$



$$(5) \quad (4 \text{ PRED}) = \text{'DRINK< SUBJ,OBJ>'}$$



$$(6) \quad s \rightarrow \begin{array}{cc} \text{NP} & \text{VP} \\ (1 \text{ SUBJ})=2 & 1 = 4 \end{array}$$

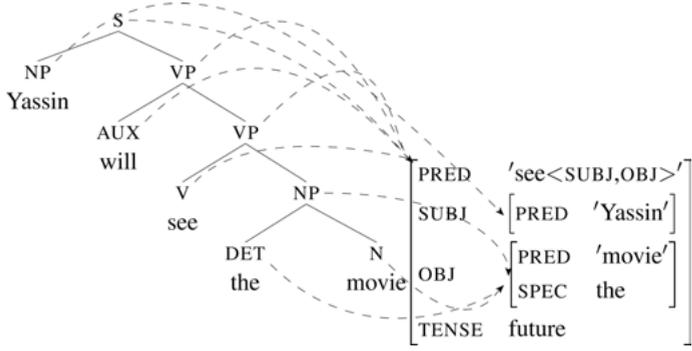


The f-structure corresponding to the NP node is labeled 2 in (4), the f-structure corresponding to the s node is labeled 1 in (6). The functional annotations are treated as equations in a mathematical system, which need to be solved. Solving the set of equations is equivalent to combining bits of f-structural information into one large f-structure as in (7).

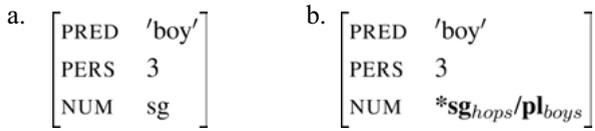
To return to our simple example, the picture in (7) shows the correspondence between the c-structure and f-structure via the φ -function. That is, the f-structure annotations on the c-structure have all been solved. The arrows from the individual c-structure nodes to parts of the f-structure are an informal illustration of the correspondence function. Note that several c-structure nodes may correspond to a single part of the f-structure.

LFG is a constraint-based theory. One effect of this is that when information from different parts of the c-structure contribute to a single part of the f-structure, the different pieces of information must be unified with one another and must therefore be compatible. For example, if a verb specifies information about its subject's person and number, these values (e.g., third person singular) must be compatible with the values for person and number provided by the subject noun. For a sentence like *The boy hops*. the subject f-structure would be as in (8a) where the number and person information are specified by both the noun *boy* and the verb *hops*. An ungrammatical sentence like *The boys hops*. would provide conflicting number values, which is shown informally in (8b).

(7)



(8)



The semantically unique PREDicate values provided by most words cannot unify, even if they appear identical superficially. This is because they carry a semantic index as part of their value and this unique index cannot unify with a different index. The index reflects the semantic reference of predicates, which is considered to be unique.

F-structures must obey three constraints: uniqueness, completeness, and coherence. Uniqueness states that for each f-structure, there is a single attribute of a given type, e.g., only one subject, only one number; if more than one attribute of a given type is required, it must be in a set (see section 3.2 on modifiers and section 3.3 on coordination). Completeness requires every argument of a predicate to be filled, e.g., if a verb requires a subject and an object, both must be present in the f-structure (**Yassin devoured*). Coherence requires governable grammatical functions, i.e. the ones licensed as arguments of predicates, to be licensed by a predicate if they appear, e.g., an object cannot appear in an f-structure unless the predicate requires it (**Yassin slept Nadya*).

The f-structures we have seen so far have included two basic grammatical relations: SUBJ(ect) and OBJ(ect). In LFG, grammatical relations are assumed as part of the syntactic inventory of every language and are referred to as grammatical functions (GF) to indicate their functional status, which is the relation of arguments and predicational elements to one another. Because GFs are assumed to not be subject to crosslinguistic variation, but are a basic part of the syntactic description language for every language, they are represented at f-structure (and only at f-structure). However, tests for different types of grammatical functionhood may play out differently across languages; see the discussion in Dalrymple (2001) for the LFG perspective (also Kroeger 2005; Croft 2001; Evans and Levinson 2009 for a different perspective). LFG assumes the GFs in (9).

(9) Grammatical Functions

- SUBJ OBJ OBJ_θ OBL(ique)_θ COMP(lement) XCOMP(lement) ADJUNCT

Dalrymple (2001: 11–27) provides a useful discussion of the GFs as well as several syntactic tests by which they can be identified. COMP and XCOMP represent clausal argu-

ments. Canonically, the COMP is used for finite clauses (e.g., the English *that*-clause) while the XCOMP encodes nonfinite, open embedded clauses. An example is the *to win* in *John wants to win*. Here, the embedded verb *win* does not have an overt subject, rather, its subject is controlled by the matrix subject *John* (see Bresnan 1982a for the classic discussion on control and complementation). Finite clauses like the English *that*-clause are considered to be closed because all of the arguments are realized internal to the clause (i.e. there is no control from the matrix clause).

The canonical example for OBJ_θ is the indirect dative object in languages like German and the second object in the English double object construction (10a). The OBL is used for prepositional phrases which are arguments of the verb. A classic example is the English indirect *to* object (10b). Other instances of OBL occur with verbs of motion as in (11), where the location is subcategorized for by the verb.

- (10) a. *Kim gave the dog a bone.*
 b. *Kim gave a bone to the dog.*
- (11) *Chris went to/in/behind the house.*

The OBJ and OBL are subscripted with a θ to indicate that these GFs are sensitive to thematic role information. That is, PP arguments as in (11) generally reflect a specific spatial semantics. Similarly, indirect objects are generally tied to goals.

In fact, there are regularities between the semantics of arguments and their syntactic expression in terms of GFs. Linking Theories in general attempt to capture these regularities (section 4).

We close this section by noting that the effect of LFG's projection architecture is that the levels of representation constrain each other mutually. That is, an analysis can only be successful if the f-structure information is complete and consistent, and if the phrase structure rules license the structure. Because the relation between c-structure and f-structure is stated in terms of a mathematical projection (φ), its inverse can also be computed. That is, not only can one see into the f-structure from the c-structure, but the f-structure can refer back to the c-structure. No level is truly primary and no information is ever lost via derivations. LFG thus falls under the label of constraint-based declarative theories of syntax (Head-driven Phrase Structure Grammar also falls under this category; see the HPSG chapter in this volume). In contrast to the fundamental derivational assumptions of GB/MP (see the Minimalism chapter in this volume), LFG assumes no derivations from one structure to another. Indeed, this is one of the characteristics which makes LFG computationally tractable.

With the basic LFG architecture and constraints on the basic c- and f-structure representations in mind, the next section examines how LFG analyzes several well known syntactic phenomena.

3. Syntactic phenomena

For purposes of concrete illustration, we go through several core syntactic phenomena in this section and show how they are analyzed in LFG. In many cases, the analyses will share aspects with other syntactic theories, especially within generative syntax and

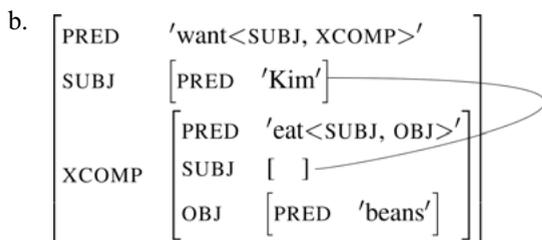
particularly within constraint-based frameworks. However, the analyses also show marked differences, which are driven by the unique architecture and assumptions of LFG. The phenomena discussed include long-distance dependencies, modifiers, coordination, agreement, and case. Argument structure and other projections are described in subsequent sections.

3.1. Long-distance dependencies

3.1.1. Functional control: Equi and raising

Functional control is described in detail in Dalrymple (2001), Bresnan (2001) and Falk (2001); the seminal article is Bresnan (1982a). In functional control, a single part of an f-structure plays two or more roles in the f-structure. Classic examples are so-called equi verbs as in (12), where the subject of *want* is identical to the subject of *eat*, but is only expressed once, namely in the matrix clause. (Equi verbs can also be analyzed as anaphoric control, see section 3.1.3)

(12) a. *Kim wants to eat beans.*



This functional sharing is expressed at the f-structure by identifying two parts of an f-structure with one another. In (12) and also generally in the theoretical literature, this is graphically illustrated by having a line that connects the two parts of the f-structure with one another.

Bresnan (1982a) shows that this type of functional control is a lexical property. That is, the type of matrix verb determines the type of functional control that happens. The verb *want*, for example, shows both subject and object control, where the matrix object controls the embedded subject, as in (13a). The verb *persuade* shows object control, as in (13b), but the verb *promise* is a subject control verb, as in (13c).

- (13) a. *Kim wanted Sandy to eat beans.*
 b. *Kim persuaded Sandy to eat beans.*
 c. *Kim promised Sandy to eat beans.*

The X in the xCOMP signifies that it is an open function which expects its subject to be controlled. Given that this type of functional control is a lexical phenomenon, the lexical entries of the verbs have to state what kind of functional control the verb allows. A

typical equation, found in subject control verbs like *promise*, is shown in (14). Object control verbs would contain the equation in (15) and verbs like *want* contain a disjunction which allows for both options. The equations basically state the subject (or object) of the matrix verb is the same as the subject of the embedded clause.

$$(14) (\uparrow\text{SUBJ}) = (\uparrow\text{XCOMP SUBJ})$$

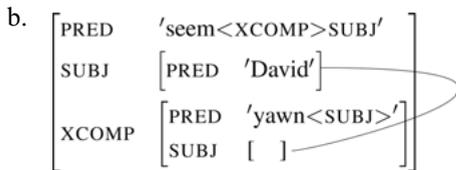
$$(15) (\uparrow\text{OBJ}) = (\uparrow\text{XCOMP SUBJ})$$

Early generative syntax argued for a distinction between equi verbs of the type above and raising verbs as in (16). The difference is that in equi verbs, the relevant arguments are licensed thematically by both the matrix and the embedded verb. For verbs like *seem*, on the other hand, it appears that no semantic selectional restrictions are imposed on the subject and that therefore an expletive subject as in (16) can be used. Verbs like *seem* were therefore identified as raising verbs.

- (16) a. *There seems to be a unicorn in the garden.*
 b. *It seems to be raining.*

In LFG, this difference in semantic content (or thematic content, as it has also been called) is expressed by writing the non-thematic (semantically empty) argument outside of the angle brackets of the subcategorization frame. This is illustrated in (17b).

- (17) a. *David seemed to yawn.*



The formal mechanism of functional control, by which two parts of an f-structure are identified with one another, however, remain the same. So the lexical entry of *seem* would contain the functional equation in (14). The main distinction posited in LFG between equi and raising verbs is a semantic one that is expressed within the subcategorization frame of the verb in question.

3.1.2. Functional uncertainty

So far, we have seen instances of functional control that are local. However, functional control can occur over several layers of embedding, as exemplified by the topicalization of *beans* in (18).

- (18) *Beans, John asked Sandy to persuade Kim to eat.*

Other dependencies that can be local as well as long-distance are *wh*-questions and relative clauses in languages like English. These dependencies, in which the interrogative, relative, or topicalized phrases do not appear in their canonical c-structure position, are also analyzed via functional control in LFG. Often, the displaced constituent can play different roles in different sentences, and these roles may be at different levels of embedding (19).

- (19) a. *Who hopped?* ($\uparrow_{\text{FOCUS-INT}} = (\uparrow_{\text{SUBJ}})$)
- b. *Who did John say hopped?* ($\uparrow_{\text{FOCUS-INT}} = (\uparrow_{\text{COMP SUBJ}})$)
- c. *What did he eat?* ($\uparrow_{\text{FOCUS-INT}} = (\uparrow_{\text{OBJ}})$)
- d. *What did John say that he ate?* ($\uparrow_{\text{FOCUS-INT}} = (\uparrow_{\text{COMP OBJ}})$)
- e. *What did he want to eat?* ($\uparrow_{\text{FOCUS-INT}} = (\uparrow_{\text{XCOMP OBJ}})$)

The control equations needed to identify the role of the displaced constituent with its GF can be listed in any individual case. However, these possibilities in theory can be infinite. (In practice, limits are imposed due to performance restrictions, for more discussion on this topic see Pullum and Scholz 2010.) LFG captures this empirical fact via functional uncertainty equations (Kaplan and Zaenen 1989). For example, Kaplan and Zaenen (1989) proposed that the rule for English topicalization is as in (20), which says that there is an XP or S' which precedes the main sentence, that this XP or S' is the overall topic of the clause and that it may correspond to some GF that may be arbitrarily deeply embedded in a series of COMPS and/or XCOMPS. The technical definition of functional uncertainty is provided by Kaplan and Zaenen (1989: 26): Functional uncertainty: $(fa) = v$ holds iff f is an f-structure, α is a set of strings, and for some s in the set of strings α , $(fs) = v$. When the string s is longer than one: $(fas) \equiv ((fa)s)$ for a symbol a and a (possibly empty) string of symbols s ; $(f\varepsilon) \equiv f$, where ε is the empty string.

$$(20) \quad s' \rightarrow \begin{array}{ccc} & \text{XP or S'} & \text{S} \\ & (\uparrow_{\text{TOPIC}}) = \downarrow & \uparrow = \downarrow \\ (\uparrow_{\text{TOPIC}}) = (\uparrow_{\{\text{COMP}, \text{XCOMP}\}^*} (\text{GF-COMP})) & & \end{array}$$

In the analysis of a given sentence, the choice of path will depend on how other arguments satisfy the subcategorization frames of the verbs. For example, in (19d) *what* cannot be the subject of *say* or *eat* because they already have subjects and coherence would be violated; however, *eat* has no object and so *what* can be equated with its object position.

Functional uncertainty paths vary cross-linguistically, reflecting island conditions and other language-particular constraints. In addition, different phenomena within a language (e.g., interrogatives, topicalization, relative clauses) may have different functional uncertainty paths. See Dalrymple (2001) for detailed discussion of functional uncertainty paths in a number of languages.

Some versions of LFG theory posit traces for certain constructions in certain languages, while others never posit traces in the c-structure. Bresnan (2001) and Falk (2001, 2007) both argue for traces in LFG for capturing phenomena such as English weak-crossover constructions and *wanna* contraction. (But see Dalrymple et al. 2001 for an alternative account of weak-crossover in terms of linear prominence constraints that do

not rely on traces.) Such accounts generally posit traces only in highly configurational languages like English which use structural positions to encode grammatical functions, instead of case marking or head marking.

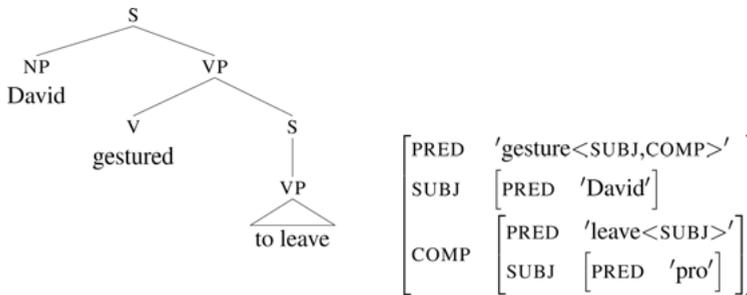
3.1.3. Anaphoric control

Functional control involves a single PRED filling two roles in the larger f-structure. However, not all cases of control are of this type. Consider (21), which at first sight would appear to involve an embedded XCOMP, just as in the examples discussed under functional control. However, here the subject (*David*) does not necessarily control the subject of the embedded clause. That is, there is arbitrary anaphoric control in that the person leaving is some person that the syntax cannot determine and that needs to be computed on the basis of discourse or world knowledge. This computation is thought of as being on a par with anaphora resolution. (LFG posits cross-linguistic binding domains within sentences for anaphora. Many accounts define appropriate f-structure domains for the binding relation in conjunction with restrictions on precedence in the c-structure. These discussions only apply tangentially to anaphoric control.)

(21) *David gestured to leave.*

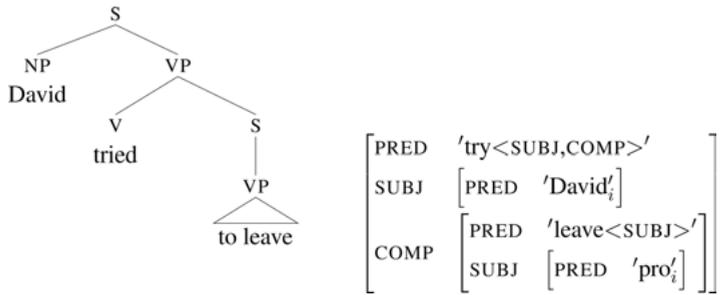
An analysis of (21) is provided in (22). The difference to functional control is that the embedded subject is not empty, but filled with a null pronominal subject (PRO) and, since the subject is filled, the embedded clause is analyzed as a COMP (a closed function) rather than an XCOMP (an open function).

(22) *David gestured to leave.*



Anaphoric control can be obligatory in certain constructions. Equi constructions have been analyzed as obligatory anaphoric control. In the case of equi, the overt controller controls a null pronominal subject of the embedded clause. This controlled subject is absent at c-structure but present in the f-structure. An example is shown in (23) from Dalrymple (2001: 324).

(23) *David tried to leave.*



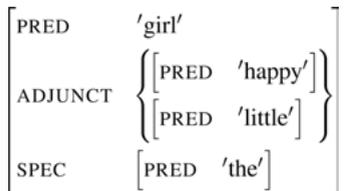
Obligatory anaphoric control has also been posited for English *tough*-constructions (Dalrymple and King 2000), as in (24).

(24) *Moths_i are tough to kill pro_i.*

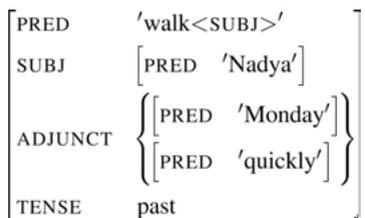
3.2. Modifiers

Modifiers or adjuncts are not subcategorized by predicates and in general multiple modifiers are allowed in a given f-structure. In order to satisfy the uniqueness requirement of f-structures, modifiers belong to a set, even when there is only one of them. Adjectival modification is illustrated in (25), clausal modification in (26).

(25) *the happy little girl*



(26) *Monday, Nadya walked quickly.*



C-structure analyses of modifiers can be as adjunction but may also appear in much flatter structures. Which type of c-structure is appropriate depends on the language and is generally determined by constituency tests such as coordination possibilities. The φ -

mapping between c-structure and f-structure for modifier sets involves specifying them as elements of the set, as in the rule for adjectival modifiers in (27), where the Kleene * represents zero or more instances of the AP.

$$(27) \quad N' \rightarrow \begin{array}{ccc} & AP^* & N \\ \downarrow \in (\uparrow \text{ADJUNCT}) & & \uparrow = \downarrow \end{array}$$

There are proposals within LFG for constraining the mapping from c- to f-structure in such a way to allow modifier annotations only in specific configurations. See, for example, Bresnan (2001).

3.3. Coordination

Coordination also involves the formation of sets in f-structure. A set will have an element for each conjunct in the coordination. The canonical example of this is resolved person and number features in noun phrase coordination, where the coordinated set may have a different person and number than the individual elements. The features which can be features of the set itself are called non-distributive features. Consider the sample coordinated NP in (28).

(28) *the dog and me*

$$\left[\begin{array}{l} \text{NUM plural} \\ \text{PERS 1} \\ \text{COORD-FORM and} \\ \left\{ \left[\begin{array}{l} \text{PRED 'dog'} \\ \text{NUM sg} \\ \text{PERS 3} \end{array} \right], \left[\begin{array}{l} \text{PRED 'I'} \\ \text{NUM sg} \\ \text{PERS 1} \end{array} \right] \right\} \end{array} \right]$$

The difference between distributive and non-distributive features is very important for phenomena like agreement (section 3.4) and case (section 3.5). If a requirement is placed on a coordinated f-structure for a distributed feature, then that requirement will distribute to each element of the set and all the elements must unify with that requirement. For example, if a verb requires a dative object and the object is coordinated, then each element in the coordinated object must be dative because case is distributive. In contrast, number and person is generally not distributive and so a verb that requires a plural subject will be compatible with an f-structure as in (28) in which the set is plural even though each conjunct is singular.

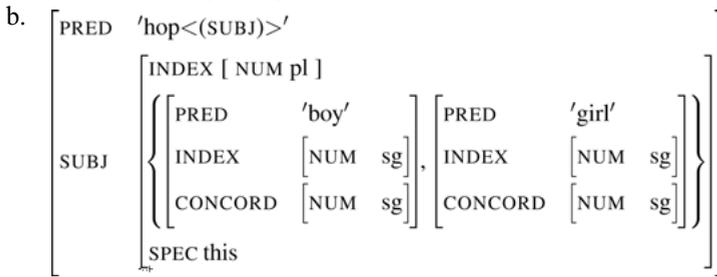
3.4. Agreement

Agreement is generally analyzed as an instance of feature unification in LFG. Both elements in the agreement relation will specify a value for a feature, e.g., singular num-

ber, and these values must be compatible, see (8). This can be done for verb-argument agreement as well as for adjective-noun agreement. Note that the feature can either be present in only one place, e.g., on the subject noun phrase, or in two places with a constraint that the values must be identical, e.g., an adjective may state that its number value is the same as that of its head noun.

A form can show agreement in one of two ways. Building on work in HPSG (Wechsler and Zlatić 2003), LFG posits two types of syntactic agreement features: CONCORD features are closely related to morphological form, while INDEX features are closely related to semantics. Different predicates will target specific feature sets. In general, CONCORD features are used for noun-phrase internal agreement, while INDEX features are used outside of the noun phrase. Consider (29).

(29) a. *This boy and girl hop.*



The verb *hop* agrees with the plural INDEX value of the coordinated NP, which is a resolved value from the agreement features on the individual conjuncts, while the determiner *this* agrees with the singular CONCORD value of each of the coordinated arguments.

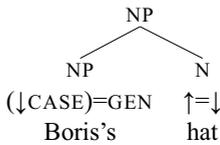
Recent LFG research has been interested in asymmetric agreement, especially variants of closest-conjunct agreement (Sadler 2003; Kuhn and Sadler 2007).

3.5. Case

LFG has its own theory of case, developed in a series of papers by Butt and King and by Rachel Nordlinger. LFG’s approach to case assignment is also often mediated by the mapping of a(argument)-structure to GFs, discussed in section 4, whereby certain cases are associated with certain thematic roles or features at a-structure, e.g., Alsina’s (1996) work on Romance. We here briefly present the inventory of case types posited by Butt and King (2003, 2005) and discuss the related proposal by Nordlinger (1998). See Butt (2006, 2008) for a more complete discussion of case in LFG, including in OT-LFG (section 6).

Positional case: Positional case is associated only with syntactic information. That is, there is assumed to be a syntactic configuration which requires a particular case marking. An example of positional case is the adnominal genitive in English (see King 1995 for examples from Russian). As shown in (30), the prenominal NP position is identified as genitive as part of the positional information in the syntax (the $\uparrow=\downarrow$ notation indicates that the noun is the head of the phrase).

(30) English Adnominal Genitives (simplified structure)



Structural and default case: Structural case is often an instance of default case and hence functions as the Elsewhere Case (Kiparsky 1973). For languages which require that all NPs have case, this can be stated as in (31a), analogous to the Case Filter in GB (Rouveret and Vergnaud 1980). If a given NP is not already associated with case due to some other part of the grammar, then default case assignment principles as in (31b–c) apply.

- (31) a. Wellformedness principle: NP: (\uparrow CASE)
 b. Default: (\uparrow SUBJ CASE) = NOM
 c. Default: (\uparrow OBJ CASE) = ACC

Default case only applies to the core grammatical relations subject and object. The other grammatical relations tend to involve specialized semantics and therefore do not involve defaults. The content of the default assignment principles may vary from language to language, but the existence of a default case for subjects and objects is expected to hold crosslinguistically.

Quirky case: The term quirky case is used only for those situations in which there is no regularity to be captured: the case assignment is truly exceptional to the system and no syntactic or semantic regularities can be detected. Under the assumption that case morphology plays a large role in the fundamental organizing principles of language, quirky case is expected to be fairly rare. Instead, case morphology is part of a coherent system, with only a few exceptions along the way. These exceptions are generally due to historical reasons and have not been eradicated or reanalysed as part of a regularization of the case system (Butt 2006).

Semantic case: The defining characteristics of semantic case in the sense of Butt and King (2003) are semantic predictability and subjection to syntactic restrictions, such as being confined to certain GFs. Indeed, most cases cannot appear on just any GF, but are restricted to one or two. Under Butt and King's (2003) analysis, most instances of case involve semantic case. This is because the bulk of the crosslinguistic case marking phenomena involve an interaction between syntactic and semantic constraints (including the quirky case found in Icelandic, which is actually mostly subject to semantic regularities). Consider the accusative/dative *ko* in Urdu. On direct objects, it signals specificity. That is, a combination of syntactic (direct objects only) and semantic factors (specificity) are involved. The *ko* can also appear on subjects and on indirect objects, as in (32). In either case, the dative is associated with a more or less abstract goal.

Within Butt and King's system, the *ko* is therefore analysed as a semantic case. Butt and King furthermore pursue a fundamentally lexical semantic approach to case. That is, lexical entries are posited for individual case markers and these lexical entries contain the bulk of the information associated with the presence of the case markers. The lexical entry for *ko*, for example, is shown in (32).

- | | |
|--|----------------------------------|
| (32) Accusative <i>ko</i> | Dative <i>ko</i> |
| (↑ CASE) = ACC | (↑ CASE) = DAT |
| (OBJ ↑) | (GOAL ↑ _{arg-str}) |
| (↑ _{sem-str} SPECIFICITY) = + | (SUBJ ↑) ∨ (OBJ _{go} ↑) |

The entry for *ko* specifies that it can be used either as an accusative or a dative. As an accusative, it can only appear on a direct object and is associated with specificity in the semantic projection. Note the use of the ↑ in the lexical entry of the case marker: the second line involves inside-out functional designation (Dalrymple 1993, 2001); the ↑ following the specification of a GF formulates a requirement that the constituent should be analysed as an object. As a dative, it can only appear on either experiencer subjects or indirect objects (OBJ_{go}) and requires a goal argument at a-structure. (32) illustrates that the information associated with case morphology interacts with information at several levels of representation, e.g., f-structure, semantic projection (section 5.4), and a-structure (section 4). (Inside-out functional designation can also be applied over functional uncertainty paths, just like the outside-in functional control discussed in section 3.1.2)

Constructive case: Further evidence for the above type of lexical approach to case comes from Australian languages. Nordlinger (1998, 2000) analyzes two phenomena found in Australian languages: discontinuous constituents as in (33) and case stacking as in (34). In the Wambaya example in (33), the NP *big dog* is a discontinuous constituent. Generally, Australian languages are known for their free word order and in Wambaya the only requirement is that there be a finite verb in second position. (1 = masculine gender class; A = transitive subject; o = object)

- (33) *galalarrinyi-ni gini-ng-a dawu bugayini-ni.* [Wambaya]
 dog.I-ERG 3SG.M.A-1.O-NFUT bite big.I-ERG
 ‘The big dog bit me.’

(Nordlinger 1998: 96)

Now also consider the phenomenon of case stacking found in Martuthunira. In (34) the word *thara* ‘pouch’ is marked with three cases: one to show that it is signalling a location, one to show that it is part of a possessive or accompanying relation to another word (the proprietive case), and one to show that it is part of (modifying) an accusative case marked noun. The word *mirtily* ‘joey’ (a baby euro – a type of kangaroo) has two cases. The proprietive shows that it stands in an accompanying relationship with another (it is with the euro), and the accusative to show that it is part of (modifying) an accusative case marked noun. Finally, ‘euro’ is accusative as the direct object of the clause, while the first person pronoun (‘I’) is nominative (unmarked). (PROP = Propriptive)

- (34) *Ngayu nhawu-lha ngurnu tharnta-a mirtily-marta-a* [Martuthunira]
 I saw-PST that.ACC euro-ACC joey-PROP-ACC
thara-ngka-marta-a.
 pouch-LOC-PROP-ACC
 ‘I saw the euro with a joey in (its) pouch.’

(Dench 1995: 60)

These facts prompted Nordlinger (1998) to formulate a new perspective on case. She sees morphology as constructing the syntax of the clause. For example, under her analysis, the Wambaya ergative *ni* carries the information that there be a subject and that it be ergative. These pieces of information are encoded as part of the lexical entry of the ergative, as shown in (35).

- (35) *ni*: (↑ CASE) = ERG
(SUBJ ↑)

With this lexical approach to case, the effect of the analysis is that the combination of information from the lexical entries of *big*, *dog* and the ergative case in (35) results in the two partial f-structures shown in (36) and (37). Both the ergative *dog* and the *big* specify that they are parts of the subject because of the information associated with the ergative case marker in (35). In addition, the *dog* serves as the head of the phrase and the *big* as an adjunct which modifies it (the details of how the adjunct analysis is accomplished are left out here).

- (36)
$$\left[\text{SUBJ} \left[\begin{array}{l} \text{PRED} \quad \text{'dog' } \\ \text{CASE} \quad \text{ERG} \end{array} \right] \right]$$

- (37)
$$\left[\text{SUBJ} \left[\begin{array}{l} \text{CASE} \quad \text{ERG} \\ \text{ADJUNCT} \quad \left\{ \text{PRED} \quad \text{'big' } \right\} \end{array} \right] \right]$$

These two sets of information are unified into the structure shown in (38) as a routine part of the clausal analysis within LFG. The problem of discontinuous constituents is thus solved by using the case morphology as a primary source of information about clausal structure.

- (38)
$$\left[\text{SUBJ} \left[\begin{array}{l} \text{CASE} \quad \text{ERG} \\ \text{PRED} \quad \text{'dog' } \\ \text{ADJUNCT} \quad \left\{ \text{PRED} \quad \text{'big' } \right\} \end{array} \right] \right]$$

The same approach also serves well for instances of case stacking. Since every case marker contributes not only a value for the case feature at f-structure, but also imposes a requirement as to what GF it must appear with, the effects of case stacking can be easily explained via the lexicalist, constructive approach to case.

4. Argument structure

In addition to the basic c- and f-structural representations, LFG's architecture potentially allows for several other projections. One standard additional projection is the a(argument)-structure. The a-structure encodes predicate-argument relationships in terms of thematic roles. These thematic roles are arranged in a thematic hierarchy, shown in (39) (based on Bresnan and Kanerva 1989).

- (39) Thematic Role Hierarchy
 agent > beneficiary > recipient/experiencer > instrument > theme/patient >
 location

The GFs as introduced in (9) are also arranged in a hierarchy. Linking is assumed to prefer a mapping between highest thematic role and highest GF (SUBJ). The default mapping is therefore straightforward: agents should map to subjects, themes should map to objects, etc. However, because languages exhibit many phenomena where this default mapping does not apply, an explicit linking or Lexical Mapping Theory was formulated in LFG to account for systematic deviations and argument alternations.

The a-structure can be formally represented as an AVM, like the f-structure (e.g., Butt 1998), but in keeping with the bulk of the literature on argument structure, representations like the following are used here: *pound* < agent theme >.

4.1. Standard LFG Mapping Theory

LFG's Lexical Mapping Theory grew out of early work like Zaenen et al.'s (1985) analysis of Icelandic and German and Levin's (1987) work on English. The discussion in this section is based on Bresnan and Zaenen (1990), Alsina and Mchombo (1993), Bresnan and Kanerva (1989), and Bresnan and Moshi (1990). Further reading and discussion can be found in Bresnan (1990) and Bresnan (1994). As in Levin's first formulation for linking, thematic roles and GFs are cross-classified by features in standard LFG, which posits just two relevant features. The feature [\pm restricted] is a semantically grounded feature, which indicates whether a given thematic role or GF is sensitive to semantic restrictions. The feature [\pm o(bjective)] marks whether thematic roles are likely to be linked to objectlike GFs. (Alsina [1996: 19] instead proposes two different features: [\pm subj(ect)] and [\pm obl(ique)].)

The [\pm r, \pm o] features classify GFs as shown in (40). The clausal COMP and XCOMP are not considered in this classification (see Berman 2003 and Dalrymple and Lødrup 2000 on the status of clausal arguments).

(40)	[−o]	[+o]
[−r]	SUBJ	OBJ
[+r]	OBL ₀	OBJ ₀

The thematic roles are classified by these same features, as shown in (41) (Bresnan and Zaenen 1990).

- (41) Classification of Thematic Roles
 Patientlike roles: [−r]
 Secondary patientlike roles: [+o]
 All others: [−o]

The possible correspondences between thematic roles and GFs are regulated by the Mapping Principles in (42) and wellformedness conditions, some of which are shown in (43)

(Bresnan and Zaenen 1990). The θ stands for thematic role and $\hat{\theta}$ refers to the highest argument on the thematic role hierarchy.

(42) Mapping Principles

a. Subject roles:

(i) $\hat{\theta}$ is mapped onto SUBJ; otherwise:
[-o]

(ii) θ is mapped onto SUBJ
[-r]

b. Other roles are mapped onto the lowest compatible function on the markedness hierarchy, where the subject is the least marked.

SUBJ < OBJ, OBL $_{\theta}$ < OBJ $_{\theta}$

(43) Wellformedness Conditions

a. Subject Condition: Every (verbal) lexical form must have a subject.

b. Function-argument biuniqueness: Each a-structure role must be associated with a unique grammatical function, and conversely.

The Function-argument biuniqueness condition in (43b) is reminiscent of GB's θ -Criterion mapping arguments to theta-roles. It has been challenged within LFG (Mohanar 1994; Alsina 1996) for not allowing the necessary flexibility to account for Argument Fusion in complex predicates (section 4.2). In addition, the Subject Condition may not hold universally (Bresnan 2001; Dalrymple 2001; Falk 2001).

The feature classifications together with the mapping and wellformedness principles constitute the essence of LFG's linking theory. Consider the following example of a transitive, a passive, an unaccusative and an unergative (taken from Bresnan and Zaenen 1990: 51–52). In (44), the transitive verb *pound* has two arguments, an agent and a theme. These are featurally classified according to (41) and then mapped to SUBJ and OBJ straightforwardly according to the mapping principles.

(44) a-structure:	<i>pound</i>	<	agent	theme	>
			[-o]	[-r]	
f-structure:			SUBJ	OBJ	

Passivization suppresses the highest thematic role, as shown in (45). The only argument available for linking into the syntax is the theme. This could potentially be linked either to a subject or an object, but because of the principle in (42), it is linked to the subject.

(45) *Passive:*

$\hat{\theta}$
∅

(46) a-structure:	<i>pound</i>	<	agent	theme	>
			[-o]	[-r]	
			∅		
f-structure:				SUBJ	

The single argument of unaccusatives is a theme, as in (47). This is classified by the feature $[-r]$ and is linked to a subject rather than an object because of the mapping principles in (42). The unaccusative situation is thus parallel to the passive in (46). In the unergative, the only argument of an unergative verb like *bark* is an agent. This is classified as a $[-o]$ thematic role and links to a subject.

(47)	a-structure: <i>freeze</i> < theme >	<i>bark</i> < agent >	
	$[-r]$	$[-o]$	
f-structure:	SUBJ	SUBJ	

The basics of LFG's mapping theory are thus very simple and yet make for a very powerful system that has been used to analyze complex case marking and argument structure phenomena in Germanic, Bantu, Romance and South Asian languages. Some of the more complex phenomena are briefly described in the remainder of this section.

4.2. Argument alternations and complex predicates

One reason LFG allows for a flexible mapping between thematic roles and GFs is because of the crosslinguistic recurrence of argument alternations. One famous alternation investigated within LFG is locative inversion in Chichewa, shown in (48) (Bresnan and Kanerva 1989; Bresnan 1994). (REC.PST = recent past)

- (48) a. *a-lendô-wo a-na-bwér-á ku-mu-dzi.* [Chichewa]
 2-visitor-2.those 2.SBJ-REC.PST-come-IND 17-3-village (visitors = subject)
 'Those visitors came to the village.'
 (Bresnan and Kanerva 1989: 2)
- b. *ku-mu-dzi ku-na-bwér-á a-lendo-wô.* [Chichewa]
 17-3-village 17.SBJ-REC.PST-come-IND 2-visitor-2 those (village=subject)
 'To the village came those visitors.'
 (Bresnan and Kanerva 1989: 2)

Chichewa is a Bantu language, which does not mark arguments via case, but instead uses a complex noun class system. The noun classes have a rough semantic/cognitive basis, but this is only rough, so the different classes are usually indicated by numbers, e.g., 2 for *visitors* and 17 for *village* in (48).

Bresnan and Kanerva (1989) amass evidence which shows that *visitors* is the subject in (48a), but not in (48b). In (48b) the subject is *village*. One piece of evidence for subject status is verb agreement: in (48a) the verb agrees with *visitors* via the class 2 marker, in (48b), the verb agrees with *village* (class 17). Locative inversion is triggered by focus, so that the location (*village*) is focused in (48b).

The possibility for locative inversion follows from the standard linking principles. The thematic roles are classified as shown in (49) via the general classification principles in (41). Both the theme and the locative could link to either SUBJ or OBL. In (49a) default linking occurs according to the mapping principles in (42): the theme is linked to the

argument structure is identified with an argument in the other. Causative morphemes and verbs are taken to have three arguments: a causer agent, a patient and a caused event. This is shown in (51). When a causative morpheme or verb is combined with another verb, it embeds this verb's argument structure in its own, as shown in (52).

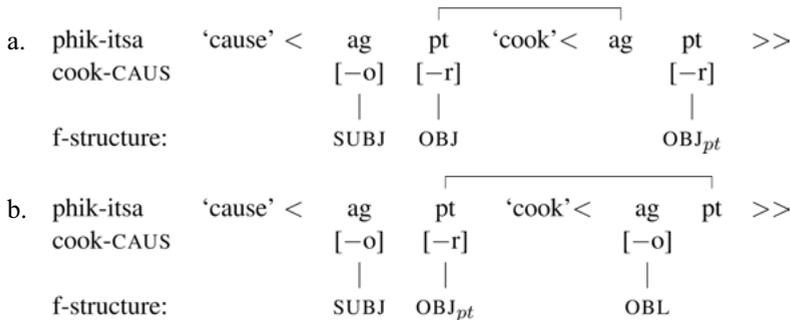
(51) CAUSE < agent patient event >

(52) CAUSE < agent patient 'cook' < agent patient >>

There are four semantic arguments in (52). However, only three arguments are expressed in the syntax. Two of these arguments fuse at argument structure before being mapped into the syntax. Alsina and Joshi (1991) posit parameters which allow fusion of the matrix patient argument with either the embedded agent or the embedded patient.

When the causee (the matrix patient) is fused with the embedded agent, the embedded agent is no longer available for linking, as shown in (53a). In this case the causee is considered to be the affected argument of the causation and is mapped to the direct object. The embedded patient is mapped to a secondary object (49a). When the matrix patient is fused with the embedded patient, then this argument is no longer available for linking and the agent of the embedded predicate is linked to an oblique (49b).

(53) Object Causee



LFG's linking theory is thus primarily concerned with the relationship between argument structure and grammatical relations (f-structure). A final point with respect to causatives and linking theories in general relates to the domain of linking. As the name already indicates, Lexical Mapping Theory assumed that the linking from thematic roles to GFs was based on a single lexical entry, i.e., was taken care of entirely within the lexical component. However, data from causatives show that argument alternations and complex argument structures can arise either in the lexicon, or in the syntax – see Alsina (1997) for an explicit comparison between the morphological causatives in Bantu and periphrastic causatives in Romance. Alsina (1996) and Butt (1995) extended LFG's linking theory to account for argument linking where the arguments are contributed by two distinct words in the syntax. The analyses assume a complex interaction between c-structure, a-structure and f-structure, where one structure cannot be built up without information present at another structure. The a-structure is thus not primary, nor is the c-structure.

That is, each of the levels of representation constrain one another within LFG's projection architecture.

Further work on complex predicates which addresses architectural and linking issues is represented by Manning and Andrews (1999) and Wilson (1999).

4.3. Incorporation of Proto-Roles

So far, we have presented the standard version of LFG's mapping theory, albeit extended into the syntax in order to capture complex predication. However, many different versions of this mapping or linking theory have been proposed. One interesting development has been the incorporation of Proto-Role information (Dowty 1991), as proposed by Zaenen (1993), for example.

Zaenen (1993) conducts a detailed study of the interaction between syntax and verbal lexical semantics in Dutch. Dutch auxiliary selection is one syntactic reflex of unaccusativity. Unaccusative verbs in Dutch select for *zijn* 'be' while unergatives select for *hebben* 'have'. Zaenen shows that semantic factors are at the root of the auxiliary selection patterns. The *have* auxiliary is associated with control over an action, whereas the *be* auxiliary is selected when an argument is affected or changed (change of state).

These properties are included in Dowty's (1991) system of Proto-Role entailments: control is a Proto-Agent property and change of state is a Proto-Patient property. Zaenen therefore proposes to incorporate Dowty's Proto-Role entailments into linking theory as shown in (54).

(54) Association of Features with Participants

1. If a participant has more patient properties than agent properties, it is marked $-r$.
2. If a participant has more agent properties than patient properties it is marked $-o$.
3. If a participant has an equal number of properties, it is marked $-r$.
4. If a participant has neither agent nor patient properties, it is marked $-o$.

(Zaenen 1993: 150,152)

The Proto-Role information allows Zaenen to dispense with thematic roles and the thematic role hierarchy. Linking is accomplished via the default association of $[\pm o, r]$ marked arguments with the GF hierarchy, as shown in (55).

(55) Association of Features with GFs

Order the participants as follows according to their intrinsic markings:

$-o < -r < +o < +r$

order the GR [grammatical functions] as follows:

SUBJ < OBJ < OBJ _{θ} (< OBL)

Starting from the left, associate the leftmost participant with the leftmost GR it is compatible with.

(Zaenen 1993: 151)

Unaccusatives and unergatives can now be analysed as follows: The single argument of unaccusatives such as *fall* has more patient properties than agent properties, is thus classified as a [-r] role, and is therefore linked to the SUBJ GF. In contrast, the single argument of an unergative such as *dance* has more agent properties than patient properties, and is therefore classified as a [-o] role and is also linked to SUBJ. The difference in auxiliary selection is sensitive to the [-r] feature, as shown in (56).

(56) Auxiliary Selection

When an -r marked participant is realized as a subject, the auxiliary is *zijn* 'be'.
(Zaenen 1993: 149)

Zaenen's linking architecture remains true to the basic spirit of linking theory, but allows a better integration of relevant semantic factors. Other approaches have also integrated Proto-Role properties into an analysis of the relationship between a-structure and GFs. In his treatment of Romance causatives, for example, Alsina revises LFG's standard linking theory considerably and also includes Proto-Role information. Ackerman's (1992) ideas are similar in spirit to Zaenen's analysis, but he offers a different way of integrating Proto-Roles for a treatment of the locative alternation. Finally, Ackerman and Moore (2001) incorporate Proto-Role properties into the selection of arguments without making explicit reference to LFG's standard linking theory, though they assume their ideas are compatible with it.

4.4. Lexical rules

Lexical rules manipulate the argument structure of lexical items in systematic ways. Lexical rules were introduced to capture regular alternations in the lexicon before a-structure was introduced as part of LFG theory (Bresnan 1982b). Some lexical rules are now replaced by a-structure alternations. However, alternations that affect GFs, e.g., SUBJ and OBJ, instead of thematic roles or argument slots must be stated as lexical rules.

The standard examples of a lexical rule is that of the passive, which rewrites the subject as NULL or as an oblique agent and rewrites the object as the subject. Thus, the lexical rules in (57) would rewrite the lexical entry in (58a) and (58b).

(57) Passive lexical rule: SUBJ → NULL
OBJ → SUBJ

- (58) a. PRED = 'persuade <SUBJ, OBJ, XCOMP>'
They persuaded the boys to leave.
b. PRED = 'persuade <NULL, SUBJ, XCOMP>'
The boys were persuaded to leave.

Rewrites like the passive rule in (57), where arguments are renamed or deleted, are easier to formulate than rules which introduce an argument, e.g., benefactive constructions. When arguments are introduced, it is unclear where in the PRED structure the new argument should appear. For this reason, such argument-adding constructions are usually dealt with within a-structure.

5. Interfaces/other projections

The f-structure is the primary syntactic projection from the c-structure. However, it is possible to have other projections off of the c-structure and off of the f-structure or other projections. Here we briefly discuss proposals for a morphosyntactic projection (section 5.1), information structure (section 5.2), prosodic structure (section 5.3), and semantic structure (section 5.4).

5.1. Morphology-syntax interface

The morphology-syntax interface can be partially factored out into an m-structure that is distinct from the f-structure. As originally formulated, the m-structure was meant to hold features that are only relevant for morpho-syntactic well-formedness while the f-structure contains features needed for syntax analysis and for semantics. The m-structure of a clause may thus vary significantly from its f-structure. In the original m-structure proposal, for example, m-structure is used to account for auxiliary stacking restrictions in English, which allows for a flatter, simpler f-structure (Butt et al. 1996).

(59) a. *Nadya will be hopping.*

b. **m-structure**

$$\left[\begin{array}{ll} \text{FORM} & \text{tensed} \\ \text{COMP} & \left[\begin{array}{ll} \text{FORM} & \text{base} \\ \text{COMP} & \left[\text{FORM} \quad \text{prog} \right] \end{array} \right] \end{array} \right]$$

c. **f-structure**

$$\left[\begin{array}{ll} \text{PRED} & \text{'hop<SUBJ>'} \\ \text{SUBJ} & \left[\text{PRED} \quad \text{'Nadya'} \right] \\ \text{TENSE} & \text{future} \\ \text{PROG} & + \end{array} \right]$$

M-structure has also been used extensively to analyze French auxiliaries and clitic distribution (Frank 1996). Most LFG analyses do not include m-structure, however, some approaches have taken up the m-structure idea and have invested it with more theoretical significance than it had originally. See Sadler and Spencer (2004) for such proposals and a more detailed discussion of the issues.

5.2. Information-structure

I(nformation)-structure encodes the clause-internal discourse information such as topic and focus. I-structure often incorporates information from the c-structure as well as the f-structure and possibly the prosodic structure. A simple example of this is shown in (60) where the non-canonical word order reflects the discourse functions of the arguments. Annotations on the c-structure rules create both the f-structure in (60b) and the i-structure in (60c).

- (60) a. *Èto plat'e šila Inna.* [Russian]
 this dress sewed Inna
 Inna-FOC sewed this dress-TOP
 'It was Inna who sewed this dress.'

b. **f-structure**

$$\left[\begin{array}{l} \text{PRED} \quad \text{'sew} < (\uparrow \text{SUBJ}), (\uparrow \text{OBJ}) > \text{' } \\ \text{SUBJ} \quad \left[\begin{array}{l} \text{PRED} \quad \text{'Inna'} \end{array} \right] \\ \text{OBJ} \quad \left[\begin{array}{l} \text{PRED} \quad \text{'dress'} \end{array} \right] \end{array} \right]$$
c. **i-structure**

$$\left[\begin{array}{l} \text{TOPIC} \quad \{ \text{Inna} \} \\ \text{FOCUS} \quad \{ \text{dress} \} \end{array} \right]$$

This is accomplished technically by having annotations such as those in (61).

- (61) IP \rightarrow $\begin{array}{cc} \text{NP} & \text{IP} \\ (\uparrow \{ \text{SUBJ} | \text{OBJ} \}) = \downarrow & \uparrow = \downarrow \\ \downarrow_i \in (\uparrow_i \text{ TOPIC}) & \uparrow_i = \downarrow_i \end{array}$

Some types of topic and focus are GFs and hence appear in the f-structure (Bresnan and Mchombo 1987). However, for many languages, a separate projection is needed in order to account for mismatches between the constituency of the f-structure and of the i-structure. For example, focused verbs cannot be encoded in the f-structure because they are the heads of their clauses and marking them as focus would result, incorrectly, in the entire clause being focused (King 1997). Note that the topic is represented as a set in (61c). This is because there could be multiple topics in clause.

There are a number of differing proposals as to how to exactly integrate the i-structure projection and what exactly should be represented at this level of analysis, see for example Choi (1999), King (1995), O'Connor (2004) and Mycock (2006).

5.3. Prosodic-structure

Work on the analysis of clitics and on discourse functions has led to the incorporation of prosodic information into the LFG architecture, generally by means of a p(rosodic)-structure projection (Butt and King 1998; O'Connor 2004; Mycock 2006). The projection is generally represented as an AVM similar to the f-structure, but there is still discussion of whether an AVM is the best form for this. For example, Bögel et al. (2009, 2010) argue for using finite-state power to create prosodically bracketed strings which can then guide c-structure formation and hence influence the f-structure. In related work, Asudeh (2009) proposes that linear string adjacency be part of the syntax-phonology interface in LFG, thereby accounting for complementizer-adjacent extraction effects without reference to traces. Dalrymple and Mycock (2011) propose a modular architecture with lexical entries containing phonological- and syntactic-forms to explain declarative questions and comma intonation in non-restrictive relative clauses.

Many analyses of clitics account for their unusual behavior by exploiting the morphology-syntax interface, instead of or in addition to using prosodic-structure for this purpose. Wescoat (2005) proposes lexical sharing to account for English auxiliary clitics,

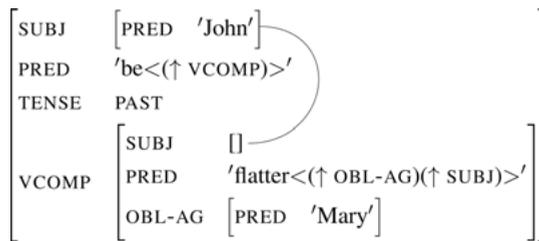
while Luís and Otoguro (2005) argue that morphology and phrase structure are separate levels of analysis. In addition, OT-LFG (section 6) can use the interaction of OT constraints in order to govern clitic placement (Estigarribia 2005; Lowe 2011).

5.4. Semantic-structure

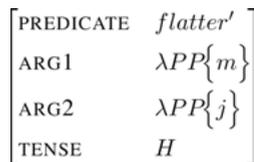
Halvorsen (1983) was the first to propose that semantic interpretation in LFG be done by projecting a s(ematic)-structure from the f-structure. In turn, this s-structure could be mapped to formulae in intensional logic and model-theoretic interpretation. Note that f-structures have since been shown to be equivalent to quasi-logical forms (QLF; van Genabith and Crouch 1996), confirming that f-structures provide a very good input for further semantic analysis.

Halvorsen's example (1) is shown simplified in (62). Note that the f-structure represents an analysis whereby English auxiliaries were taken to embed a vCOMP (infinitive clause), an analysis that is no longer standard in LFG – rather a flat f-structure is now assumed with the auxiliary only registering tense/aspect information (Butt et al. 1999).

- (62) a. *John was flattered by Mary.*
 b. f-structure



- c. s-structure



- d. formula of intensional logic

$flatter'_*(m, j)$

In Halvorsen's original example, the complex f-structure is projected into the flat s-structure in (62c), which can then be further processed into an intensional logic formula, as shown in (62d).

Halvorsen and Kaplan (1988) also argue for a s-structure but propose a co-description analysis whereby the s-structure is not projected in its entirety from the f-structure. Instead it is created simultaneously as a parallel projection to the f-structure, with certain

mutually constraining factors. Co-description analyses have enjoyed a steady popularity in LFG.

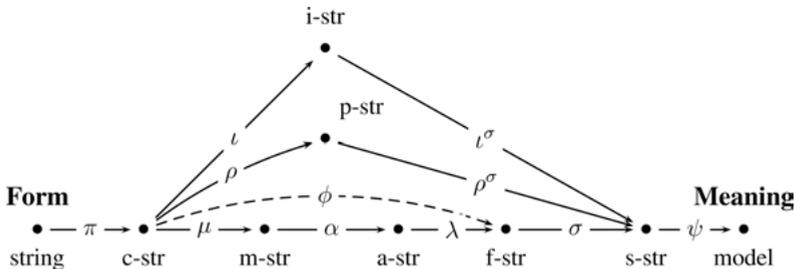
In newer approaches, however, semantic analyses based on LFG f-structures have largely abandoned the s-structure approach and instead use Glue semantics (Dalrymple 1999). Under this approach, the meanings of words are separate from the mechanisms which combine them. Lexical entries contain meaning constructors that specify how the word contributes to the meaning of larger syntactic constituents. The meanings of the larger constituents are derived using linear-logic deduction on the meanings of the parts. Combining all of the premises according to a resource logic (linear logic) results in the meaning of an utterance. Because the composition is governed by this logic, it does not have to follow the rules of phrasal (e.g., c-structure) composition. Glue semantics is resource sensitive, because in the deduction each premise is consumed as it is used and all premises must be consumed. Extensive examples of Glue semantic analyses for different syntactic and semantic constructions can be found in Dalrymple (2001).

Within the computational community yet another approach to semantic construction has recently been developed, namely a system called XFR (Crouch et al. 2011) involving ordered rewrite rules, which are used to efficiently and robustly produce semantic structures from f-structures (Crouch 2006; Crouch and King 2006). The resulting semantics gives a flat representation of the sentence’s predicate argument structure and the semantic contexts in which those predications hold. These semantic structures in turn are input to additional ordered rewrite rules which produce Abstract Knowledge Representations (AKRs) (Bobrow et al. 2005; Bobrow et al. 2007).

5.5. The overall LFG projection architecture

We have now briefly introduced a number of different proposals for additional projections. Within the LFG community, there are a number of proposals as to how these various different structures relate to one another. A constant is that f-structure is a projection from the c-structure, as in the original proposal (Bresnan 1982b). A possible architecture is represented in (63). Here, the c-structure and f-structure are modulated by the m(orphosyntactic)-structure and the a(rgument)-structure. In addition, the s(ematic)-structure comprises information from the f-structure and the c-structure, with the p(ro-sodic)-structure and i(nformation)-structure mapping between the c-structure and s-structure. There are many minor variants of the architecture shown in (63); see Asudeh (2006: 369) for discussion.

(63) The Correspondence Architecture (Asudeh 2006)



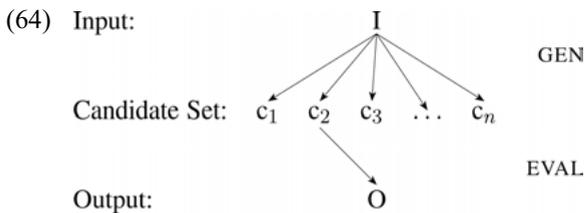
6. OT-LFG

An additional architectural component was added to LFG with the advent of Optimality Theory (OT). OT was originally formulated to solve problems with respect to alignment constraints in prosodic morphology (McCarthy and Prince 1993). The establishment of OT as a serious domain of investigation within syntax is due mainly to articles by Jane Grimshaw (Grimshaw 1997) and Joan Bresnan (Bresnan 1998). In particular, Bresnan showed how OT could be used in conjunction with standard LFG.

The next section introduces the basic architecture and assumptions of OT, and the following section shows how LFG theory can be integrated with OT.

6.1. OT basics

Within OT, the goal is to determine an optimal output (surface form) with respect to a given input. The optimal output is picked from a set of candidates that compete with one another. The competition between the candidates is resolved by an evaluation of constraint violations, as shown in (64) (adapted from Vogel 2001).



The nature of the input is still in need of precise definition in much of OT. Grimshaw's (1997) original paper assumed that the input encompasses the basic argument structure of a predicate, and a specification of tense/aspect. In later work (Grimshaw and Samek-Lodovici 1998), the focus/topic specifications were included as part of the input. A typical input might look as in (65), where the argument structure of *give* is specified, along with information about which argument is the topic, and which is in focus.

(65) *give*(x,y,z), x=topic, z=focus, x=Kim, z=dog, y=bone

6.2. Optimality Theory and LFG

In OT-LFG (Bresnan 2000; Kuhn 2003), the input is assumed to be an underspecified f-structure in the sense that the GFs are not as yet specified. An example for the transitive verb *drive* is shown in (66).

(66)
$$\left[\begin{array}{ll} \text{PRED} & \text{'drive} < \text{GF}_1, \text{GF}_2 > \\ \text{GF}_1 & [] \\ \text{GF}_2 & [] \end{array} \right]$$

The skeletal f-structure inputs are passed on to a function GEN, which generates a set of possible output candidates that could correspond to the input. Within OT-LFG, GEN is assumed to be equivalent to a standard LFG grammar. LFG grammars can be used to both parse and generate; so the idea is that an underspecified input as in (66) is passed on to an existing grammar for English. This searches through its rule space and produces all possible pairings of c-structures and surface strings that could correspond to the input f-structure. Kuhn (2003) shows that this is computationally viable.

Quite a bit of work is done within OT-LFG, some of the early landmark contributions are collected in Sells (2001).

7. Computational issues and resources

Right from its inception, LFG was designed as a theory and formalism whose mathematical basis is solid and well-understood. This property means that LFG is particularly suitable for computational linguistic research and there has been computational linguistic work based on LFG for over twenty years. Interest in using LFG in computational linguistics, as well as natural language processing applications is increasing steadily (see the chapter on computational syntax in this volume).

Perhaps the most visible computational effort involving LFG is the Parallel Grammar (ParGram) group (Butt et al. 1999; Butt et al. 2002), which implements LFG grammars of different languages on the XLE grammar development platform (Crouch et al. 2011). The guiding motivation of ParGram is an effort at parallel analyses across languages using parallel implementation techniques. That is, much effort goes into sorting through possible alternative analyses and feature spaces for phenomena across languages and trying to agree on f-structure analyses that are as parallel as possible across a diverse number of languages. Grammars that have been developed so far include Arabic, English, French, German, Hungarian, Indonesian, Japanese, Malagasy, Murrinh-Patha, Norwegian, Tigrinya, Turkish, Urdu and Welsh. The English and the Japanese grammars have been used for industrial purposes in terms of developing query systems and the Norwegian grammar was used in a machine translation project named LOGON.

Since f-structures are already very close to semantic forms (see section 5.4), the idea in LFG is that if analyses are kept as parallel across languages as possible, then applications like machine translation should be able to produce good results more easily (Frank 1999).

The bulk of the computational work done within LFG is (naturally) symbolic and rule-based. However, statistical methods can be integrated in several ways, i.e. to pick the most likely parse or sentence to be generated among a forest of possibilities (Riezler and Maxwell 2006; Cahill et al. 2007; Graham et al. 2009).

All of the projections discussed above are in principle implementable via the grammar development platform XLE, though this is rarely done in practice, with most computational grammars confining themselves to just c- and f-structures. However, an OT-projection is routinely used in the computational grammars (Frank et al. 2001; Crouch et al. 2011). Its purpose is to help constrain the grammar by dispreferring or preferring certain rules or lexical items over others.

8. Psycholinguistic research

LFG has also been used as the basis for psycholinguistic research, though not to the extent that was once thought. The first standard reference for LFG work, namely Bresnan (1982b), contains papers on psycholinguistics by Marilyn Ford and Steven Pinker. The basic tenets of LFG continued to inform their psycholinguistic research (e.g., Levelt 1989; Pinker 1989; Gropen et al. 1991). However, most of the psycholinguistic LFG-related work seems to have taken place in the 1980s and early 1990s. An exception are recent publications by Ford and Bresnan (Ford and Bresnan 2013; Bresnan and Ford 2010), which take up Bresnan's recent work on stochastic approaches to syntax (e.g., Bresnan 2007).

9. Conclusion

From its inception, LFG has had the goal of combining linguistic insights with solid mathematical foundations, computational tractability and implementability (Dalrymple et al. 1995). Much work in LFG has focused on typological diversity, with major efforts in a large number of language families. This is reflected in some of the core areas of research such as case and agreement systems, causatives and complex predicates, coordination, and anaphora. LFG minimally posits two levels of representation: the c-structure and the f-structure. The c-structure encodes linear order, constituency and hierarchical relations while the f-structure focuses on the dependency structure of a clause. The mapping between the two is realized in terms of a mathematical function and need not be one-to-one. This fact allows for a flexible architecture which can deal with long-distance dependencies and other complex linguistic phenomena in a straight-forward and elegant manner.

A broad range of theoretical, descriptive and computational linguists work within LFG, with some work also being done in neuro- and psycholinguistics. Several current textbooks are available (Bresnan 2001; Dalrymple 2001; Falk 2001), as is a description of the ParGram grammar development effort (Butt et al. 1999).

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