Information Packaging in a Categorial Perspective

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Abstract

Vallduví (1992,1993,1994) identifies a set of informational primitives adapted from the traditional notions *focus/ground* and *topic/comment*, and shows how these are manifested in several languages, with an emphasis on Catalan and English. Cross-language comparison shows that in expressing information packaging—i.e., the structuring of propositional content in function of the speaker's assumptions about the hearer's knowledge and attentional state—, different languages exploit word order and prosody in different ways. In other words, one single informational construct is realized by drastically different structural means across languages. Thus for English it can be argued that, roughly speaking, information packaging is structurally realized by means of alternative intonational contours of identical strings. Catalan, on the other hand, is resistant to such an analysis: it has a constant prosodic structure, and realizes information packaging by means of string order permutations.

The present paper investigates how the various structural realizations of information packaging can be handled by a sign-based categorial grammar formalism. The above generalizations provide confirmation that information packaging involves syntax as well as prosody: hence any attempt to reduce informational aspects to either syntax (for Catalan) or prosody (for English, cf. Steedman (1991,1992,1993)) is inadequate from a cross-linguistic perspective. Accordingly, the present paper treats the different forms of information packaging in Catalan and English by means of a both intonationally/syntactically and semantically/informationally interpreted version of the double non-associative Lambek calculus of Moortgat and Morrill (1991), enriched with the unary operators of Moortgat (1994).

On the intonational/syntactic side, this yields a systematic account of the range of variation in the structural realization of information packaging displayed by Catalan and English. The present treatment of focus differs from other extensions of standard Lambek calculus such

as Oehrle (1991), Van der Linden (1991) and Moortgat (1993) in that it lacks focus operators, but employs 'defocus' operators instead.

On the semantic/informational side, the proofs of the calculus are interpreted into Muskens' (1993,1994) type-theoretical version of Discourse Representation Theory (see Kamp (1981), Kamp and Reyle (1993)), a deviation from Vallduví (1992,1993,1994)—who uses file systems à la Heim (1982,1983)—which is motivated in Dekker and Hendriks (1994).

1 Introduction

The basic idea of information packaging, a notion introduced in Chafe (1976) which is the object of study of Vallduví (1992, 1993, 1994), is that speakers do not present information in an unstructured way, but that they provide a hearer with detailed instructions on how to manipulate and integrate this information according to their beliefs about the hearer's knowledge and attentional state:

> To ensure reasonably efficient communication, [... t]he speaker tries, to the best of his ability, to make the structure of his utterances congruent with his knowledge of the listener's mental world. (Clark and Haviland (1977), p. 5.)

For instance, sentences such as (1) and (2) are truth-conditionally equivalent in that they express the same proposition, but each of them 'packages' this proposition in a different way:[1]

(1) The boss hates BROCCOLI

(2) The boss HATES broccoli

Typically, speakers will use (1) if the hearer at the time of utterance knows nothing about or is not attending to the boss' relation to broccoli, while they will use (2) if the hearer at the time of utterance knows that there exists a relation between the boss and broccoli, is attending to this relation, but does not know what it is. Apparently, speakers are sensitive to such differences in the hearer's knowledge and attentional state.

Truth-conditionally equivalent sentences that encode different information packaging instructions are not mutually interchangeable *salva felicitate*

[1]Small caps are used for lexical items that bear a (focal) H* pitch accent (see below).

in a given context of utterance: e.g., of the above sentences, only the first one is a felicitous answer to the question *What does the boss hate?* It is this context-sensitivity that has traditionally placed information packaging within the realm of pragmatics.

Vallduví's account of information packaging is a combination of two influential earlier pragmatic approaches, the 'topic/comment' and the 'focus/ground' approach.

The topic/comment approach splits the set of subexpressions of a sentence into a 'topic', the—typically sentence-initial—part that expresses what the sentence is about, and a 'comment', the part that expresses what is said about the topic. Topics are points of departure for what the sentence conveys, they link it to previous discourse. Sentences may be topicless: so-called presentational or news sentences consist entirely of a comment.

According to the focus/ground approach, sentences consist of a 'focus' and a 'ground'.[2] The focus is the informative part of the sentence, the part that (the speaker believes) makes some contribution to the hearer's mental state. The ground is the non-informative part of the sentence, the part that anchors the sentence to what is already established or under discussion in (the speaker's picture of) the hearer's mental state. Although sentences may lack a ground altogether, sentences without focus do not exist.

Notice, by way of example (adopted from Dahl (1974)), that the sentence *John drinks beer* gives rise to the parallel topic/comment and focus/ground partitions indicated in (3) if it answers the questions *What about John? What does he do?*, whereas it induces the partitions specified by (4) in the interrogative context *What about the John? What does he drink?*

(3)

topic	comment
John	*drinks beer*
ground	focus

(4)

topic	comment	
John	*drinks*	*beer*
ground		focus

The fact that the two informational articulations correspond to different partitions in (4) shows that neither of them is by itself capable of capturing all the informational distinctions present in the sentence. Therefore, Vallduví proposes to conflate the two traditional binomial articulations of

[2]The ground is also known as 'presupposition' and as 'open proposition'.

focus/ground and topic/comment into a single trinomial and hierarchical one. The core distinction is the one between new information and anchoring, between focus and ground. Besides, the ground is further divided into the 'link', which corresponds approximately to the topic in the traditional topic/comment approach, and the 'tail'.[3] In a picture:

(5)

<table>
<tr><td>(topic)</td><td colspan="2">(comment)</td></tr>
<tr><td>link</td><td>tail</td><td></td></tr>
<tr><td colspan="2">ground</td><td>focus</td></tr>
</table>

Given this articulation, the answer *John drinks beer* to the questions *What about John? What does he drink?* will receive the following analysis:

(6)

John	*drinks*	*beer*
link	tail	

<table>
<tr><td colspan="2">ground</td><td>focus</td></tr>
</table>

Roughly speaking, the various parts—focus and ground, link and tail—of a sentence S have the following informational functions. The focus encodes I_S, the information of S, which can be metaphorically described as ϕ_S, the proposition expressed by S, minus K_H, the information (the speaker presumes) already present in the hearer's model. The ground performs an ushering role—it specifies the way in which I_S fits in the hearer's model: links indicate where I_S should go by denoting a location in the hearer's model, and tails indicate how I_S fits there by signaling a certain mode of information update.

Of course, talking about ushering information to some location in the hearer's model presupposes that the hearer's model has some sort of internal structure. In this respect, Vallduví purports to

> agree with Heim that there has to be some additional internal structure in the hearer's model of the common ground that plays an important role in natural language interpretation, even if this internal structure is of tangential relevance in truth value computation. It is the internal structure of information states which is, in fact, crucially exploited by the different information-packaging

[3] The hierarchy does not imply constituency or (even) continuity. In particular, the two parts (link and tail) of the ground may not constitute a linear unit at the surface. Sentences may have more than one link—cf. the Catalan example [$_{\rm L}$*El bròquil*][$_{\rm L}$*a l'amo*][$_{\rm F}$*l'hi van regalar*] (Vallduví (1992), p. 60)—and more than one element may constitute the tail.

strategies used by speakers in pursuing communicative efficiency. (Vallduví (1994), § 2.)

Actually, Vallduví follows Heim (1982, 1983) in assuming that the information in the hearer's model is organized in files, i.e., collections of file cards. Each file card represents a discourse entity: its attributes and its links with other discourse entities are recorded on the card in the form of conditions. A discourse entity may be known to the hearer but not salient at the time of utterance, it may be salient at the time of utterance, it may be completely new to the hearer, it may be inferable from what the hearer knows, etc. Discourse entities mediate between referring expressions (noun phrases) and entities in the real world: indefinite noun phrases prompt hearers to create a new file card, and definite noun phrases incite them to retrieve an already existing file card. Both definites and pronouns denote already existing file cards, but pronouns denote salient file cards, while (other) definites refer to non-salient ones.

File change comprises the above aspects of file card management, but it also involves content update, i.e., the incorporation of information conveyed by a given sentence into records on novel and familiar file cards, and this is where Vallduví lets information packaging come in. Links are associated with so-called GOTO declarations. In file change semantics, the target location of such a declaration is a file card *fc*. A tail points at an information record—normally a (possibly underspecified) condition—on such a file card, record(*fc*), and indicates that it has to be *modified* (or further specified) by the focus information I_S of the sentence. The associated instruction type is called UPDATE-REPLACE. In the absence of a tail, the focus information I_S of a sentence is simply *added* at the current location. The associated instruction type is called UPDATE-ADD. Sentences may lack links and tails (recall that the focus is the only non-optional part of a sentence), so the following four sentence types can be distinguished:

(7) *a.* focus
b. link-focus
c. focus-tail
d. link-focus-tail

We will discuss the syntactic and prosodic realization of these structures in more detail below (see §3 and §4).[4] Presently, we concentrate on the

[4]Links, tails and foci are specified by means of $[_{L} \ldots]$, $[_{T} \ldots]$ and $[_{F} \ldots]$ brackets, respectively. Accented items in foci and links are written in small caps (H* pitch accent)

respective (compound) instruction types with which they are associated:

(8) *a.* UPDATE-ADD(I_S)
b. GOTO(fc)(UPDATE-ADD(I_S))
c. UPDATE-REPLACE(I_S,RECORD(fc))
d. GOTO(fc)(UPDATE-REPLACE(I_S,RECORD(fc)))

The first two instruction types in (8) can be illustrated with the following examples:

(9) [$_L$The **boss**][$_F$hates BROCCOLI]

(10) [$_F$He always eats BEANS]

Example (9) is a link-focus construction, and therefore associated with a GOTO(fc)(UPDATE-ADD(I_S)) instruction. The link *the boss* specifies a locus of update fc, viz., the card representing the boss—say, card #125. The focus *hates broccoli* specifies the information I_S that has to be added to this card. Suppose that broccoli is represented by card #136. Then, passing over some formal details, the UPDATE-ADD(I_S) instruction associated with the focus *hates broccoli* amounts to adding the condition 'hates(136)(125)' to the locus of update, i.e. the boss' card #125. Moreover, the record '$\boxed{\leadsto 125}$', a Hypercard-style link pointing to the locus of update, is added to card #136, rendering the condition 'hates(136)(125)' on card #125 'accessible' from card #136.

Example (10), an all-focus construction, is associated with a simple UPDATE-ADD(I_S) instruction. Here, this instruction involves the addition of the focus information I_S that the value of the current card always eats beans. That is, if it is interpreted immediately after the preceding example and if we leave its adverbially modified transitive verb phrase unanalyzed for simplicity, it amounts to adding the condition 'always eats beans(125)' to card #125.

The presence of a tail in a sentence signals a mode of update different from the straightforward UPDATE-ADD(I_S) instruction. A tail indicates that a (possibly underspecified) record on a file card has to be replaced (or specified further). The material in the tail serves the purpose of determining

and boldface (L+H* pitch accent), respectively.

which record. Suppose, for example, that (11) is a reaction to the statement *Since John is dead, we can now split his inheritance*:

(11) I hate to spoil the fun, but $[_{F}$he is NOT$][_{T}$dead$]$

With this focus-tail example, the speaker instructs the hearer to replace the record on the current locus of update—card #15, say, for John—expressing that the value of card #15 is dead by one saying that he is not dead. In short, the tail serves to highlight a condition on file card #15, the one saying its value is dead. This condition is then modified in the way specified by the material in the focus.

Something similar is assumed to be going on in the link-focus-tail example (12). A newly appointed temp asks the executive secretary whether it was a good idea to order broccoli for the boss. The executive secretary gives the following answer:

(12) $[_{L}$The **boss**$][_{F}$HATES$][_{T}$broccoli$]$

The idea is that the temp has an underspecified record on his card for the boss, which says that the boss has some attitude towards broccoli. The lack of information about the nature of this attitude is reflected by a blank in the record, and it is this blank which is replaced by 'hates' after hearing the executive secretary's answer (12).

Different languages choose different structural means to spell out the same informational interpretations. Vallduví argues that empirical support for the above representation of information packaging is supplied by languages such as Catalan and Italian. These languages package their information in a much more salient way than, for example, English. Thus, while informational interpretations may be expressed exclusively by prosodic means in English, information packaging instructions in Catalan are straightforwardly reflected in syntax.

In English, one and the same string may be assigned different intonational phrasings in order to realize different informational interpretations. The focus is associated with a H* pitch accent (written in small caps), links are marked by a L+H* pitch accent (written in boldface), and tails are structurally characterized by being deaccented. As a consequence, the focal pitch accent may be realized on different positions in the sentence. This is illustrated by the sentences (14), (16) and (18), which can be construed as answers to the respective questions (13), (15) and (17):

(13) What did you find out about the company?

(14) [$_F$The boss hates BROCCOLI]

(15) What did you find out about the boss?

(16) [$_L$The **boss**][$_F$hates BROCCOLI]

(17) What does the boss feel about broccoli?

(18) [$_L$The **boss**][$_F$HATES][$_T$broccoli]

In terms of the multistratal syntactic theory adopted by Vallduví (1992), Catalan focal elements remain within the so-called 'core clause', but ground elements are 'detached' to a clause-peripheral position. In particular, links are detached to the left, and non-link ground elements undergo right-detachment. As a result of detaching both links and tails, the core clause (CC) is left, at the surface, containing only the focus of the sentence:

(19) [links [$_{CC}$ FOCUS] tails]

Consider the Catalan counterparts (20), (21) and (22) of (14), (16) and (18), respectively. The all-focus sentence (20) displays the basic verb-object-subject word order. In (21) and (22), the link subject *l'amo* has been detached to the left. In (22), moreover, the tail object *el bròquil* has been detached to the right, leaving a clitic (*l'*) in the focal core clause. Note that intonational structure plays a part in Catalan too, albeit 'a rather lame one' (Vallduví (1993), p. 33): a focal H* pitch acent is associated with the last item of the core clause.

(20) [$_F$Odia el bròquil L'AMO]

(21) [$_L$L'amo][$_F$odia el BRÒQUIL]

(22) [$_L$L'amo][$_F$l'ODIA][$_T$el bróquil]

In view of these phenomena, the categorial account of information packaging to be given below will deviate from the categorial analysis of information packaging in English as presented in Steedman (1991, 1992, 1993).

Steedman's starting point is the observation that the 'Combinatorial Categorial' notion of syntactic surface structure that has been induced to explain coordination in English[5] yields various alternative (semantically equivalent) constituency bracketings—actually: different proof unfoldings—for identical strings of syntactic categories. He argues that the notion of 'intonational structure' that has been postulated for assigning phrasal intonation to sentences can be subsumed under this notion of syntactic surface structure. The claim is that in spoken utterances, intonation helps to determine which of the many possible syntactic derivations is intended, and that, moreover, the interpretations of the major constituents that arise from these derivations constitute the 'theme' (ground) and 'rheme' (focus) of the utterance: each major constituent of syntactic surface structure is assigned an informational function according to the intonational tune that it bears. The aforementioned subsumption of intonational structure under syntactic surface structure is simply enforced by imposing the *Prosodic Constituent Condition*: combination of two syntactic categories via a syntactic combinatory rule is allowed (if and) only if their prosodic categories can also combine via a prosodic combinatory rule.[6] Of course, it cannot be denied that such a theory 'offers the possibility that phonology and syntax are one system' (Steedman (1991), p. 272). But the simple requirement that syntactic structures and intonational structures be isomorphic does not exactly bring this possibility closer to reality. For that matter, Steedman notes that the prosodic and syntactic combinatory rules need not, and usually

[5]See Steedman (1985, 1990). Combinatory Categorial Grammar is a subsystem of the associative Lambek (1958) calculus. It contains forward and backward functional application, composition and type-raising, as well as Cut.

[6]Lexical expressions (*John*, *walks*, ...) are assigned syntactic categories (np, s/np, ...); pitch accents (L+H*, H*), boundary tones (LH%, LL%, L) and the null tone ($\emptyset$) are assigned prosodic categories. (Viz., L+H* $\rightsquigarrow$ $Theme/Bh$, H* $\rightsquigarrow$ $(Utterance/Theme)/bl$, H* $\rightsquigarrow$ $(Utterance\backslash Theme)/Bl$, LH% $\rightsquigarrow$ Bh, LL% $\rightsquigarrow$ Bl, L $\rightsquigarrow$ bl, and $\emptyset \mapsto X/X$, where X can match any category. Thus in Steedman (1992), slightly modifying Steedman (1991).) The exact formal status of the syntactic and the prosodic structure remains somewhat implicit. Steedman only notes that 'the association of tones with words at the lowest level of the derivation does not mean that they are associated with them in the lexicon. The tones are properties of prosodic phrases, whose extent and limits they define. [...T]he phonological categories define an autonomous or 'autosegmental' level of intonational structure [...]. However, the *Prosodic Constituent Condition* [...] expresses the fact that the structures are isomorphic, and can therefore be considered as annotations to a single structure' (1991, pp. 283–4). Note, nevertheless, that *if* the structures are really *iso*(and-not-just-homo)morphic, nothing seems to oppose itself against their association in the lexicon. Observe that some such association is required for assigning a well-founded interpretation to the pronoun 'their' in the Prosodic Constituent Condition itself.

will not, be the same. E.g., the syntax of Steedman (1991) accommodates both forward and backward functional application, composition and type-raising, but its prosody permits just application and a 'very restricted form of forward functional composition'.[7] Since the Prosodic Constituent Condition admits only derivations consistent with both prosodic and syntactic information, this 'has the sole effect of excluding certain derivations [and hence informational interpretations—HH] for spoken utterances that would be allowed for the equivalent written sentences' (Steedman (1992), p. 31).

The latter also points to a limitation inherent in Steedman's approach. Observe that it may adequately be applied to a language such as English, insofar as information packaging in English is structurally realized by means of alternative intonational contours of identical strings of syntactic categories, but that it will not be capable of providing an account of information packaging in Catalan, where different informational interpretations are expressed by different strings of syntactic categories. Therefore, the categorial system of § 2 (and §4) below will not contain autonomous or 'autosegmental' levels of prosodic and syntactic structure (whether or not defined as annotations to a single structure). Instead, it will deal with intonation and word order at one and the same level.

The present proposal differs as well from categorial analyses of focus that employ extensions of the Lambek calculus such as Van der Linden (1991), Oehrle (1991) and Moortgat (1993).

Acccording to Van der Linden (1991), the phenomenon of focus resembles generalized quantification in that focused constituents are logico-semantic functors which take the non-focused part of the sentence as their argument while retaining their thematic behaviour. Semantically, focused constituents are lifted expressions: if a constituent with interpretation α of type τ occurs as a focus, it is interpreted as $\lambda P_{(\tau,t)}\textsc{focus}(\alpha, P)$ of type $((\tau, t), t)$, where 'FOCUS is a semantic operation the content of which should at least entail exhaustiveness and some form of newness' (Van der Linden (1991), § 2).

Oehrle (1991) discusses earlier work on the association with focus of particles such as *only* and *even*, quantificational adverbs (Rooth (1985)), as well as generic sentences in general (Krifka (1991)), and mentions the attractiveness of semantically interpreting such focus-sensitive operators as relations between the interpretations of the ground and the focus of the sentence: OPERATOR(GROUND)(FOCUS). Moreover, following Jacobs (1983) and Krifka

[7] '[...] because the whole point of the prosodic categories is to PREVENT composition across the theme/rheme boundary' (Steedman (1991), p. 278).

(1991), Oehrle suggests that, instantiating this tripartite scheme, the focal pitch accent H* itself can be interpreted as an illocutionary operator.

Moortgat (1993) also proposes to interpret the focus intonation pattern as an operator. Somewhat simplified, his treatment of focus-as-binding interprets the focus intonation contour as an operator f which, when applied to a focused constituent which is 'normally' interpreted as α of type τ, yields $f(\alpha)$ of type $((\tau, t), t)$, where $f(\alpha) = \lambda v_{(\tau,t)}[v(\alpha) \wedge \textsc{foreground}(\alpha)(v)]$. So, semantically, the focus type transition is associated with 'a recipe which to the truth-functional content adds an element of information structuring in terms of a foreground/background opposition' (Moortgat (1993), § 4.2).

The assumption made in Van der Linden (1991) (see also Szabolccsi (1981, 1983) and Svoboda and Materna (1987)) that focus is not only an information-packaging primitive but also an implicit truth-conditional exhaustiveness operator—even in the absence of overt exhaustiveness operators like *only*—is criticized by Vallduví (1992). He concludes convincingly that 'the claim that focused constituents truth-conditionally entail exhausitiveness leads to extreme positions' (Vallduví (1992), p. 170).

Besides, Vallduví (1992) and Vallduví and Zacharski (1993) pay ample attention to the semantic analyses of 'association with focus' that are discussed in Oehrle (1991). Whereas Jacobs (1983), Rooth (1985), Krifka (1991) and others have argued that the quantificational structure of so-called focus-sensitive operators is crucially determined by the traditional pragmatic focus-ground partition (it has even been claimed that the partition primarily serves to provide this structure), Vallduví and Zacharski show that this is not necessarily the case: 'association with (pragmatic) focus' is not an inherent semantic property of these operators, which may express their semantics on partitions other than the focus-ground one—witness obvious cases of association with subsegments of the informational focus, with links, and with other parts of the ground.

Note that the dissociation of the pragmatic focus-background distinction from issues of exhaustiveness and focus-sensitivity dispels the need of analyzing focused constituents as operators which semantically take scope over the non-focused parts of the sentence. This can be considered an advantage. As sentences may lack links and tails, such analyses do not immediately reflect the core status of the focus, which is the only non-optional part of a sentence. In some sense, all-focus sentences are basic, while the cases where there is a ground are derived from this basic all-focus structure. Besides, a closer look at the various information packaging instructions (8) that correspond to the different sentence-types in (7) above suggests even a reverse approach, since it is precisely the GOTO and UPDATE-REPLACE instructions induced by links and tails that take scope over the focus information I_S of the sentence. Accordingly, the categorial analysis of information packaging in §3 and §4 below will not employ focusing operators. Instead, it will make use of 'defocusing' operators that license the presence of links and tails.

2 Sign-Based Categorial Grammar

In the Gentzen presentation of the associative Lambek calculus **L** (Lambek (1958)), explicit application of the structural rule of Associativity is usually compiled away in the way in which the sequent language is defined. Thus, given some finite set ATOM of atomic categories (none of which coincides with a compound category (A/B), $(B\backslash A)$ or $(A \bullet B)$), the set CAT of categories based on ATOM is defined as the smallest set such that ATOM $\subseteq$ CAT, and if $A \in$ CAT and $B \in$ CAT, then $(B\backslash A) \in$ CAT, $(A/B) \in$ CAT and $(A \bullet B) \in$ CAT. (Outermost brackets of categories will be omitted.) On this basis, a sequent is then defined as an expression $T \Rightarrow C$, where T is a finite non-empty *sequence* of categories and $C \in$ CAT. So, $T = C_1, \ldots, C_n$, where $n > 0$ and $C_i \in$ CAT for all i such that $1 \leq i \leq n$. The sequence of left-hand side categories T is called the antecedent of the sequent $T \Rightarrow C$, and the single right-hand side category C is its consequent, or goal. In this set-up, the axioms and inference rules of the associative Lambek calculus **L** are as follows (where A, B, C denote arbitrary categories and S, T, U, V arbitrary finite sequences of categories, of which S and T are non-empty):

(23) $$\frac{}{A \Rightarrow A}\ [Ax] \qquad \frac{T \Rightarrow A \quad U, A, V \Rightarrow C}{U, T, V \Rightarrow C}\ [Cut]$$

(24) $$\frac{T \Rightarrow B \quad U, A, V \Rightarrow C}{U, T, B\backslash A, V \Rightarrow C}\ [\backslash L] \qquad \frac{B, T \Rightarrow A}{T \Rightarrow B\backslash A}\ [\backslash R]$$

(25) $$\frac{T \Rightarrow B \quad U, A, V \Rightarrow C}{U, A/B, T, V \Rightarrow C}\ [/L] \qquad \frac{T, B \Rightarrow A}{T \Rightarrow A/B}\ [/R]$$

(26) $$\frac{U, A, B, V \Rightarrow C}{U, A \bullet B, V \Rightarrow C}\ [\bullet L] \qquad \frac{S \Rightarrow A \quad T \Rightarrow B}{S, T \Rightarrow A \bullet B}\ [\bullet R]$$

Observe that reading antecedents of sequents as sequences involves an interpretation of the comma as a connective of variable arity, rather than as a binary one. Alternatively, we can read antecedents of sequents as *structured* *terms*, where the set TERM of structured terms is the smallest set such that CAT $\subseteq$ TERM, and if $\Gamma \in$ TERM and $\Delta \in$ TERM, then $[\Gamma, \Delta] \in$ TERM. Under this approach, the associative Lambek calculus **L** can be formulated as follows. The axioms and inference rules in (23) through (26) get the respective counterparts in (27) through (30) below (where A, B, C denote categories, Γ and Δ (and $\Delta', \Delta'', \Delta'''$) structured terms, and $\Gamma\{\Delta\}$ represents a structured term Γ containing a distinguished occurrence of the structured subterm Δ):

(27) $$\frac{}{A \Rightarrow A}\,[Ax] \qquad \frac{\Delta \Rightarrow A \quad \Gamma\{A\} \Rightarrow C}{\Gamma\{\Delta\} \Rightarrow C}\,[Cut]$$

(28) $$\frac{\Delta \Rightarrow B \quad \Gamma\{A\} \Rightarrow C}{\Gamma\{[\Delta, B\backslash A]\} \Rightarrow C}\,[\backslash L] \qquad \frac{[B, \Gamma] \Rightarrow A}{\Gamma \Rightarrow B\backslash A}\,[\backslash R]$$

(29) $$\frac{\Delta \Rightarrow B \quad \Gamma\{A\} \Rightarrow C}{\Gamma\{[A/B, \Delta]\} \Rightarrow C}\,[/L] \qquad \frac{[\Gamma, B] \Rightarrow A}{\Gamma \Rightarrow A/B}\,[/R]$$

(30) $$\frac{\Gamma\{[A, B]\} \Rightarrow C}{\Gamma\{A \bullet B\} \Rightarrow C}\,[\bullet L] \qquad \frac{\Gamma \Rightarrow A \quad \Delta \Rightarrow B}{[\Gamma, \Delta] \Rightarrow A \bullet B}\,[\bullet R]$$

In addition, there are explicit structural rules AL and AR of Left and Right Associativity:

(31) $$\frac{\Gamma\{[\Delta', [\Delta'', \Delta''']]\} \Rightarrow C}{\Gamma\{[[\Delta', \Delta''], \Delta''']\} \Rightarrow C}\,[AL] \quad \frac{\Gamma\{[[\Delta', \Delta''], \Delta''']\} \Rightarrow C}{\Gamma\{[\Delta', [\Delta'', \Delta''']]\} \Rightarrow C}\,[AR]$$

The system that consists of the axioms and rules in (27) through (30) but *lacks* the structural rules in (31) is the Gentzen presentation of the *non*-associative Lambek calculus **NL** (Lambek (1961)).

The calculus **D** which will be used in the present paper is essentially just a doubling of **NL**. It was introduced in Moorgat and Morrill (1991) in order to account for head/non-head dependency as an autonomous dimension of linguistic structure.[8] The head/non-head opposition is captured by decomposing the product into a left-dominant and a right-dominant variant and obtaining residuation duality for both variants.

[8]Thus dependency structure may cross-cut semantic function/argument structure, since it is not defined in terms of it. Cf. Barry and Pickering (1990) for an alternative, derived notion of head. The notation used below is quite different from the one employed in Moorgat and Morrill (1991).

Accordingly, the set CAT of categories based on ATOM is defined as the smallest set such that:

(32) ATOM $\subseteq$ CAT; and
if $A \in$ CAT and $B \in$ CAT, then $(B\backslash_{*}A) \in$ CAT, $(A\overset{*}{/}B) \in$ CAT,
$(A{}^{*}\!\bullet B) \in$ CAT, $(B\overset{*}{\backslash}A) \in$ CAT, $(A/_{*}B) \in$ CAT and $(A\bullet^{*}B) \in$ CAT.

The set TERM of structured terms is defined as the smallest set such that:

(33) CAT $\subseteq$ TERM; and
$[\Gamma\,,\Delta] \in$ TERM and $[\Gamma\,\text{`}\,\Delta] \in$ TERM if $\Gamma \in$ TERM and $\Delta \in$ TERM.

The calculus **D** has the axioms and inference rules specified in (34) through (40) below (again, A, B, C denote categories, Γ and Δ structured terms, and $\Gamma\{\Delta\}$ represents a structured term Γ containing a distinguished occurrence of the structured subterm Δ):

(34)
$$\frac{}{A \Rightarrow A}\,[Ax] \qquad \frac{\Delta \Rightarrow A \quad \Gamma\{A\} \Rightarrow C}{\Gamma\{\Delta\} \Rightarrow C}\,[Cut]$$

(35)
$$\frac{\Delta \Rightarrow B \quad \Gamma\{A\} \Rightarrow C}{\Gamma\{[\Delta\,, B\backslash_{*}A]\} \Rightarrow C}\,[\backslash_{*}L] \qquad \frac{[B\,,\Gamma] \Rightarrow A}{\Gamma \Rightarrow B\backslash_{*}A}\,[\backslash_{*}R]$$

(36)
$$\frac{\Delta \Rightarrow B \quad \Gamma\{A\} \Rightarrow C}{\Gamma\{[\Delta\,\text{`}\,B\overset{*}{\backslash}A]\} \Rightarrow C}\,[\overset{*}{\backslash}L] \qquad \frac{[B\,\text{`}\,\Gamma] \Rightarrow A}{\Gamma \Rightarrow B\overset{*}{\backslash}A}\,[\overset{*}{\backslash}R]$$

(37)
$$\frac{\Delta \Rightarrow B \quad \Gamma\{A\} \Rightarrow C}{\Gamma\{[A\overset{*}{/}B\,, \Delta]\} \Rightarrow C}\,[\overset{*}{/}L] \qquad \frac{[\Gamma\,, B] \Rightarrow A}{\Gamma \Rightarrow A\overset{*}{/}B}\,[\overset{*}{/}R]$$

(38)
$$\frac{\Delta \Rightarrow B \quad \Gamma\{A\} \Rightarrow C}{\Gamma\{[A/_{*}B\,\text{`}\,\Delta]\} \Rightarrow C}\,[/_{*}L] \qquad \frac{[\Gamma\,\text{`}\,B] \Rightarrow A}{\Gamma \Rightarrow A/_{*}B}\,[/_{*}R]$$

(39)
$$\frac{\Gamma\{[A\,, B]\} \Rightarrow C}{\Gamma\{A{}^{*}\!\bullet B\} \Rightarrow C}\,[{}^{*}\!\bullet L] \qquad \frac{\Gamma \Rightarrow A \quad \Delta \Rightarrow B}{[\Gamma\,, \Delta] \Rightarrow A{}^{*}\!\bullet B}\,[{}^{*}\!\bullet R]$$

(40)
$$\frac{\Gamma\{[A\,\text{`}\,B]\} \Rightarrow C}{\Gamma\{A\bullet^{*}B\} \Rightarrow C}\,[\bullet^{*}L] \qquad \frac{\Gamma \Rightarrow A \quad \Delta \Rightarrow B}{[\Gamma\,\text{`}\,\Delta] \Rightarrow A\bullet^{*}B}\,[\bullet^{*}R]$$

Lambek (1958) proved a *Cut* elimination theorem for the associative calculus **L**: the set of theorems of the system is not decreased by removing the *Cut* rule from the set of its inference rules. Since the premises of the other inference rules contain a strictly smaller number of occurrences of \, / and • than their conclusions, every sequent has only finitely many *Cut*-free derivations, so that **L** is decidable: for any sequent, the proof procedure will terminate after finitely many steps with an answer to the question whether the sequent is derivable. The proof of this *Cut* elimination result, which involves the definition of an algorithm the execution of which transforms any proof in finitely many steps into a *Cut*-free proof of the same conclusion sequent, is easily adapted to the non-associative calculi **NL** and **D**.

We will use the calculus **D** in a so-called sign-based set-up, which takes its inspiration from Oehrle's (1988, 1993) work on generalized compositionality for multidimentional linguistic objects and which shares characteristics with HPSG (Head-driven Phrase Structure Grammar)—see Pollard and Sag (1987, 1994). That is: the calculus will function as the proof-theoretic engine of a grammar that represents sequents as composed of multidimensional *signs*, i.e., objects of the following form:

(41) prosodic term ◃ category ▹ semantic term

More formally, SIGN, the set of signs, is the following set:

(42) $\{\varphi \triangleleft C \triangleright \gamma \mid \varphi \in \text{PROS and } C \in \text{CAT and } \gamma \in \text{SEM}\}$

The sets PROS, CAT and SEM are defined in (49) below, (32) above, and (45) below, respectively. The set TERM of structured terms is defined as the smallest set such that:

(43) $\text{SIGN} \subseteq \text{TERM}$; and
$[\Gamma\,,\Delta] \in \text{TERM}$ and $[\Gamma\,`\,\Delta] \in \text{TERM}$ if $\Gamma \in \text{TERM}$ and $\Delta \in \text{TERM}$.

For a structured term Γ, the sequence $s(\Gamma)$ of signs of Γ is defined as follows:

(44) $s(\alpha \triangleleft C \triangleright \tau) = \alpha \triangleleft C \triangleright \tau$; and
$s([\Gamma\,,\Delta]) = s([\Gamma\,`\,\Delta]) = s(\Gamma), s(\Delta)$.

The sign-based grammar will derive sequents $\Gamma \Rightarrow S$, where Γ is a structured term (as defined in (43)) and S is a sign (see (42)). Its axioms and rules are listed in (50) through (63) below. Observe that apart from the respective assignments $\varphi\triangleleft$ and $\triangleright\gamma$ of prosodic and semantic terms to categories, this system is identical to the calculus **D** specified in (34) through (40) above.

Let us first concentrate on the assignment of semantic terms. These terms are expressions of the formal language of typed lambda calculus. In the (Church-style) typed lambda calculus we will consider, every term has a unique type. Within this theory, all the usual logical operators (truth, falsity, Boolean connectives and quantifiers) are definable in terms of application, abstraction and identity.

The set T of types consists of primitive types and types formed out of them by means of certain operations. We will consider the primitive types e and t (of entities and truth values, respectively), as well as the compound types $\langle\sigma\rightarrow\tau\rangle$ (the type of functions from objects of type σ to objects of type τ) and $\langle\sigma,\tau\rangle$ (the type of pairs consisting of an object of type σ and an object of type τ).

The formal language to represent objects in such structures is a family of sets of semantic terms indexed by the types:

(45) $\quad \text{SEM} = (\text{SEM}_\tau)_{\tau\in T}$

There are simple terms and compound terms. For each type τ, the simple terms of that type include some (possibly empty) set CON_τ of constants, plus an infinite set VAR_τ of variables:

(46) $\quad \text{VAR}_\tau = \{v_{i,\tau} \mid i \in \mathbb{N}\}$

The remaining terms are obtained by defining SEM—i.e., $(\text{SEM}_\tau)_{\tau\in T}$—as the smallest collection such that for all types π, ρ, σ, τ:[9]

(47) (*a*) $\text{VAR}_\tau \cup \text{CON}_\tau \subseteq \text{SEM}_\tau$;
(*b*) $[[\alpha](\beta)] \in \text{SEM}_\tau$ if $\alpha \in \text{SEM}_{\langle\sigma\rightarrow\tau\rangle}$ and $\beta \in \text{SEM}_\sigma$ (*application*);
(*c*) $\lambda v\, \alpha \in \text{SEM}_{\langle\sigma\rightarrow\tau\rangle}$ if $v \in \text{VAR}_\sigma$ and $\alpha \in \text{SEM}_\tau$ (*abstraction*);
(*d*) $[\alpha = \beta] \in \text{SEM}_t$ if $\alpha \in \text{SEM}_\tau$ and $\beta \in \text{SEM}_\tau$ (*identity*);
(*e*) $[\alpha \star \beta] \in \text{SEM}_{\langle\sigma,\tau\rangle}$ if $\alpha \in \text{SEM}_\sigma$ and $\beta \in \text{SEM}_\tau$ (*pairing*); and
(*f*) $E^\star_{u,v}(\alpha,\beta) \in \text{SEM}_\tau$ if $u \in \text{VAR}_\pi, v \in \text{VAR}_\rho, \alpha \in \text{SEM}_{\langle\pi,\rho\rangle}$ and $\beta \in \text{SEM}_\tau$ (*letting*).

Every category occurrence in a derivable sequent $\Gamma \Rightarrow S$ is assigned a semantic term. The type of this term depends on the category. For atomic

[9] If no confusion is likely to arise, we will write terms $[[\alpha](\beta)]$ as $[\alpha(\beta)]$ or as $\alpha(\beta)$. In $\lambda v\,\alpha$, the λ-operator binds the occurrences of v in α. The term constructor $E^\star_{u,v}(\alpha,\beta)$ is introduced in Benton, Bierman, Hyland and De Paiva (1992) and Hyland and De Paiva (1993), where it is written as **let** α **be** $u\star v$ **in** β. The present notation is due to Troelstra (1993). In $E^\star_{u,v}(\alpha,\beta)$, the $E^\star$-operator binds the occurrences of u and v in the term β.

categories C, some type assignment $\textsc{type}(C)$ is assumed, which is extended to compound categories by the stipulation that $\textsc{type}(A\backslash_* B) = \textsc{type}(A\backslash^* B)$ $= \textsc{type}(A/^* B) = \textsc{type}(A/_* B) = \langle\textsc{type}(B)\rightarrow\textsc{type}(A)\rangle$ and that $\textsc{type}(A{}^*{\bullet}B)$ $= \textsc{type}(A{\bullet}^*B) = \langle\textsc{type}(A)\,,\textsc{type}(B)\rangle$. The categories in the antecedent Γ of a derivable sequent $\Gamma \Rightarrow S$ are assigned distinct variables of the appropriate types, while a possibly complex term of type $\textsc{type}(C)$ is assigned to the single category C in the consequent S.

In (50) through (63) below, the respective expressions α, β and γ denote terms of type $\textsc{type}(A)$, $\textsc{type}(B)$ and $\textsc{type}(C)$. The expressions u, v, w, x and y represent variables of type $\textsc{type}(A)$, $\textsc{type}(B)$, $\textsc{type}(C)$, $\langle\textsc{type}(B)\rightarrow\textsc{type}(A)\rangle$ and $\langle\textsc{type}(A)\,,\textsc{type}(B)\rangle$, respectively. The expression $\gamma[u\rightarrow\alpha]$ denotes the result of substituting the term α for all free occurrences of the variable u in the term γ. As above, Γ and Δ denote structured terms, and the expression $\Gamma\{\Delta\}$ is meant to represent a structured term Γ containing a distinguished occurrence of the structured subterm Δ. Note that, semantically, the *Ax* clause amounts to identity, the *Cut* rule to substitution, the rules $\backslash_* L, \backslash^* L, /^* L, /_* L$ to application, the rules $\backslash_* R, \backslash^* R, /^* R, /_* R$ to abstraction, the rules ${}^*{\bullet}L, {\bullet}^*L$ to pairing, and the rules ${}^*{\bullet}R, {\bullet}^*R$ to letting.

In the context of a proof, we will assume that all variables u assigned to an axiom instance, all variables x introduced in the conclusion of a $\backslash_* L, \backslash^* L, /^* L, /_* L$ inference, and all variables y introduced in the conclusion of a ${}^*{\bullet}L, {\bullet}^*L$ inference are different. Observe that, as a consequence (a) the variables $v_1, \ldots v_n$ assigned to the categories occurring in the antecedent Γ of a sequent $\Gamma \Rightarrow S$ are all different; (b) these variables $v_1, \ldots v_n$ make up the free variables of the term γ assigned to the category in the consequent S; and (c) each variable $v_1, \ldots v_n$ occurs exactly once in γ.

It can be noted here that a semantic version of the aforementioned decidability result for the calculus $\mathbf{D}$ can be shown to hold: the result of applying Lambek's *Cut* elimination algorithm to a derivation is a *Cut*-free derivation which is semantically equivalent to the original derivation in that the semantic term assigned to the consequent of its conclusion sequent reduces to the semantic term assigned to the consequent of the conclusion of the original derivation via finitely many applications of one of the reductions $[\lambda x\, \alpha](\beta) = \alpha[x\rightarrow\beta]$, $E^\star_{x,y}(\alpha' \star \alpha'', \beta) = \beta[x\rightarrow\alpha', y\rightarrow\alpha'']$ and $\beta[w\rightarrow E^\star_{x,y}(z,\alpha)] = E^\star_{x,y}(z, \beta[w\rightarrow\alpha])$. Consequently, we only have to consider the *Cut*-free derivations of a sequent in order to obtain all its semantic interpretations.

The assignment of prosodic terms proceeds in an analogous—though type-free—fashion. First, the simple prosodic terms include a (possibly empty) set PCON of prosodic constants, as well as an infinite set PVAR of prosodic variables:

(48) $\text{PVAR} = \{f_i \mid i \in \mathbb{N}\}$

Next, the set PROS of prosodic terms is defined as the smallest set satisfying the following:

(49) $\text{VAR} \cup \text{CON} \subseteq \text{PROS}$;
$\langle \phi \,, \psi \rangle \in \text{PROS}$ if $\phi \in \text{PROS}$ and $\psi \in \text{PROS}$ (*head left*); and
$\langle \phi \,` \psi \rangle \in \text{PROS}$ if $\phi \in \text{PROS}$ and $\psi \in \text{PROS}$ (*head right*).

Furthermore, every category occurrence in a derivable sequent $\Gamma \Rightarrow S$ is assigned a prosodic term: the categories in the antecedent Γ are assigned distinct prosodic variables, and the single category in the consequent S is assigned a possibly complex prosodic term. In (50) through (63) below, the expressions φ and ψ denote arbitrary prosodic terms, and f, g and h represent prosodic variables. In the prosodic domain, we let the expression $\varphi[\psi \to \chi]$ denote the result of replacing all occurrences of the subterm ψ in φ by occurrences of the term χ. This may involve more than mere substitution for prosodic variables. Thus, prosodically, axioms amount to identity, the rules *Cut*, ${}_{*}\backslash L, \backslash^{*} L, /^{*} L, /_{*} L$ to substitution, the rules ${}_{*}\backslash R, \backslash^{*} R, /^{*} R, /_{*} R$ to taking a subterm, and the rules ${}^{*}\!\bullet R$ and $\bullet^{*} R$ to the construction of a head left and head right term, respectively, but the respective rules ${}^{*}\!\bullet L, \bullet^{*} L$ involve the replacement of the compound prosodic terms $\langle f \,, g \rangle$ and $\langle f \,` g \rangle$ by a prosodic variable h.

In the context of a proof, we will assume that all prosodic variables f, g and h assigned to an axiom instance, introduced in the conclusion of a ${}_{*}\backslash L, \backslash^{*} L, /^{*} L, /_{*} L$ inference and introduced in the conclusion of a ${}^{*}\!\bullet L, \bullet^{*} L$ inference, respectively, are different. This has the same consequences as the parallel assumption concerning semantic variables: the prosodic variables $f_1, \ldots f_n$ assigned to the antecedent categories of a sequent $\Gamma \Rightarrow S$ are all different, they make up the variables of the prosodic term φ assigned to the consequent category, and they occur exactly once in φ.

A prosodic version of the *Cut* elimination theorem holds as well, since application of the *Cut* elimination algorithm leads to a *Cut*-free derivation which is prosodically equivalent to the original derivation in that the prosodic term assigned to the consequent of its conclusion sequent is *identical* to the prosodic term assigned to the consequent of the conclusion of the original derivation. Consequently, we only have to consider the *Cut*-free derivations of a sequent in order to obtain all its prosodic interpretations.

(50) $$\frac{}{f \triangleleft A \triangleright u \Rightarrow f \triangleleft A \triangleright u}\ [Ax]$$

(51) $$\frac{\Delta \Rightarrow \psi \triangleleft A \triangleright \alpha \quad \Gamma\{f \triangleleft A \triangleright u\} \Rightarrow \varphi \triangleleft C \triangleright \gamma}{\Gamma\{\Delta\} \Rightarrow \varphi[f{\to}\psi] \triangleleft C \triangleright \gamma[u{\to}\alpha]}\ [Cut]$$

(52) $$\frac{\Delta \Rightarrow \psi \triangleleft B \triangleright \beta \quad \Gamma\{f \triangleleft A \triangleright u\} \Rightarrow \varphi \triangleleft C \triangleright \gamma}{\Gamma\{[\Delta\,, g \triangleleft B\backslash_{*}A \triangleright x]\} \Rightarrow \varphi[f{\to}\langle\psi\,, g\rangle] \triangleleft C \triangleright \gamma[u{\to}x(\beta)]}\ [\backslash_{*}L]$$

(53) $$\frac{\Delta \Rightarrow \psi \triangleleft B \triangleright \beta \quad \Gamma\{f \triangleleft A \triangleright u\} \Rightarrow \varphi \triangleleft C \triangleright \gamma}{\Gamma\{[\Delta\,\text{‘}\, g \triangleleft B\backslash^{*}A \triangleright x]\} \Rightarrow \varphi[f{\to}\langle\psi\,\text{‘}\, g\rangle] \triangleleft C \triangleright \gamma[u{\to}x(\beta)]}\ [\backslash^{*}L]$$

(54) $$\frac{\Delta \Rightarrow \psi \triangleleft B \triangleright \beta \quad \Gamma\{f \triangleleft A \triangleright u\} \Rightarrow \varphi \triangleleft C \triangleright \gamma}{\Gamma\{[g \triangleleft A/^{*}B \triangleright x\,, \Delta]\} \Rightarrow \varphi[f{\to}\langle g\,, \psi\rangle] \triangleleft C \triangleright \gamma[u{\to}x(\beta)]}\ [/^{*}L]$$

(55) $$\frac{\Delta \Rightarrow \psi \triangleleft B \triangleright \beta \quad \Gamma\{f \triangleleft A \triangleright u\} \Rightarrow \varphi \triangleleft C \triangleright \gamma}{\Gamma\{[g \triangleleft A/_{*}B \triangleright x\,\text{‘}\, \Delta]\} \Rightarrow \varphi[f{\to}\langle g\,\text{‘}\, \psi\rangle] \triangleleft C \triangleright \gamma[u{\to}x(\beta)]}\ [/_{*}L]$$

(56) $$\frac{[f \triangleleft B \triangleright v\,, \Gamma] \Rightarrow \langle f\,, \varphi\rangle \triangleleft A \triangleright \alpha}{\Gamma \Rightarrow \varphi \triangleleft B\backslash_{*}A \triangleright \lambda v.\alpha}\ [\backslash_{*}R]$$

(57) $$\frac{[f \triangleleft B \triangleright v\,\text{‘}\, \Gamma] \Rightarrow \langle f\,\text{‘}\, \varphi\rangle \triangleleft A \triangleright \alpha}{\Gamma \Rightarrow \varphi \triangleleft B\backslash^{*}A \triangleright \lambda v.\alpha}\ [\backslash^{*}R]$$

(58) $$\frac{[\Gamma\,, f \triangleleft B \triangleright v] \Rightarrow \langle\varphi\,, f\rangle \triangleleft A \triangleright \alpha}{\Gamma \Rightarrow \varphi \triangleleft A/^{*}B \triangleright \lambda v.\alpha}\ [/^{*}R]$$

(59) $$\frac{[\Gamma\,\text{‘}\, f \triangleleft B \triangleright v] \Rightarrow \langle\varphi\,\text{‘}\, f\rangle \triangleleft A \triangleright \alpha}{\Gamma \Rightarrow \varphi \triangleleft A/_{*}B \triangleright \lambda v.\alpha}\ [/_{*}R]$$

(60) $$\frac{\Gamma\{[f \triangleleft A \triangleright u\,, g \triangleleft B \triangleright v]\} \Rightarrow \varphi \triangleleft C \triangleright \gamma}{\Gamma\{h \triangleleft A{}^{*}\!\bullet B \triangleright y\} \Rightarrow \varphi[\langle f\,, g\rangle{\to}h] \triangleleft C \triangleright E^{\star}_{u,v}(y, \gamma)}\ [{}^{*}\!\bullet L]$$

(61) $$\frac{\Gamma\{[f \triangleleft A \triangleright u\,\text{‘}\, g \triangleleft B \triangleright v]\} \Rightarrow \varphi \triangleleft C \triangleright \gamma}{\Gamma\{h \triangleleft A\bullet^{*} B \triangleright y\} \Rightarrow \varphi[\langle f\,\text{‘}\, g\rangle{\to}h] \triangleleft C \triangleright E^{\star}_{u,v}(y, \gamma)}\ [\bullet^{*}L]$$

(62) $$\frac{\Gamma \Rightarrow \varphi \triangleleft A \triangleright \alpha \quad \Delta \Rightarrow \psi \triangleleft B \triangleright \beta}{[\Gamma, \Delta] \Rightarrow \langle\varphi\,, \psi\rangle \triangleleft A{}^{*}\!\bullet B \triangleright \alpha \star \beta}\ [{}^{*}\!\bullet R]$$

$$(63)\qquad \frac{\Gamma \Rightarrow \varphi \triangleleft A \triangleright \alpha \quad \Delta \Rightarrow \psi \triangleleft B \triangleright \beta}{[\Gamma\, ‘\, \Delta] \Rightarrow \langle \varphi\, ‘\, \psi \rangle \triangleleft A \bullet^{*} B \triangleright \alpha \star \beta}\,[\bullet^{*} R]$$

In keeping with the set-up outlined above, we will assume that the lexicon is a collection of lexical signs $\varphi \triangleleft C \triangleright \gamma$, where φ is a prosodic term, C is syntactic category, and γ is a semantic term of type $\text{TYPE}(C)$.

Given a lexicon L, we will say that a (possibly compound) sign $\varphi' \triangleleft C \triangleright \gamma'$ is in the language of L iff for some derivable sequent $\Gamma \Rightarrow \varphi \triangleleft C \triangleright \gamma$ with $s(\Gamma)$ $= f_1 \triangleleft C_1 \triangleright v_1, \ldots, f_n \triangleleft C_n \triangleright v_n$, there are $\varphi_1 \triangleleft C_1 \triangleright \gamma_1 \in L, \ldots, \varphi_n \triangleleft C_n \triangleright \gamma_n \in L$ such that $\varphi \lceil f_1 \rightarrow \varphi_1, \ldots, f_n \rightarrow \varphi_n \rceil = \varphi'$ and $\gamma\,[\,v_1 \rightarrow \gamma_1, \ldots, v_n \rightarrow \gamma_n\,] = \gamma'$.

The sequence $s(\Gamma)$ of signs of a structured term Γ has been defined in (44) above. The expression $\gamma\,[\,v_1 \rightarrow \gamma_1, \ldots, v_n \rightarrow \gamma_n\,]$ denotes the result of simultaneously and respectively substituting $v_1, \ldots, v_n$ by $\gamma_1, \ldots, \gamma_n$ in γ. The prosodic substitution $\varphi \lceil f_1 \rightarrow \varphi_1, \ldots, f_n \rightarrow \varphi_n \rceil$ is defined as follows.

$$
(64)\qquad
\begin{array}{lcl}
\langle \varphi , \psi \rangle \lceil \vec{s} \rceil & = & \varphi \lceil \vec{s} \rceil \;\; \psi \llbracket \vec{s} \rrbracket \\
\langle \varphi\, ‘\, \psi \rangle \lceil \vec{s} \rceil & = & \varphi \llbracket \vec{s} \rrbracket \;\; \psi \lceil \vec{s} \rceil \\
f \lceil \vec{s}, f \rightarrow \mathit{term}, \vec{s}\,' \rceil & = & \text{TERM} \\
\langle \varphi , \psi \rangle \llbracket \vec{s} \rrbracket & = & \varphi \llbracket \vec{s} \rrbracket \;\; \psi \llbracket \vec{s} \rrbracket \\
\langle \varphi\, ‘\, \psi \rangle \llbracket \vec{s} \rrbracket & = & \varphi \llbracket \vec{s} \rrbracket \;\; \psi \llbracket \vec{s} \rrbracket \\
f \llbracket \vec{s}, f \rightarrow \mathit{term}, \vec{s}\,' \rrbracket & = & \text{term}
\end{array}
$$

(65) Kim loves MIA $\triangleleft\, s \triangleright \text{LOVE}(m)(k)$

Observe, for example, that the sign (65) belongs to the language of lexicon $L = \{\mathit{Kim} \triangleleft n \triangleright k, \mathit{loves} \triangleleft n \overset{*}{\backslash} (s /_{*} n) \triangleright \text{LOVE}, \mathit{Mia} \triangleleft n \triangleright m\}$, because the sequent $[f \triangleleft n \triangleright x\, ‘\, [g \triangleleft n \overset{*}{\backslash} (s /_{*} n) \triangleright y\, ‘\, h \triangleleft n \triangleright z]] \Rightarrow \langle f\, ‘\, \langle g\, ‘\, h \rangle\rangle \triangleleft s \triangleright y(z)(x)$ is derivable from the axiom instances (67) through (68), as shown in (66):

$$(66)\qquad \frac{(67) \qquad \dfrac{(68) \qquad\qquad (69)}{[g' \triangleleft s /_{*} n \triangleright y'\, ‘\, h \triangleleft n \triangleright z] \Rightarrow \langle g'\, ‘\, h \rangle \triangleleft s \triangleright y'(z)}\,[/_{*} L]}{[f \triangleleft n \triangleright x\, ‘\, [g \triangleleft n \overset{*}{\backslash} (s /_{*} n) \triangleright y\, ‘\, h \triangleleft n \triangleright z]] \Rightarrow \langle f\, ‘\, \langle g\, ‘\, h \rangle\rangle \triangleleft s \triangleright y(z)(x)}\,[\overset{*}{\backslash} L]$$

(67) $f \triangleleft n \triangleright x \Rightarrow f \triangleleft n \triangleright x$

(68) $h \triangleleft n \triangleright z \Rightarrow h \triangleleft n \triangleright z$

(69) $g'' \triangleleft s \triangleright y'' \Rightarrow g'' \triangleleft s \triangleright y''$

In addition, the antecedent of the conclusion of (66) yields the set of signs $\{f \triangleleft n \triangleright x, g \triangleleft n \overset{*}{\backslash}(s \underset{*}{/} n) \triangleright y, h \triangleleft n \triangleright z\}$, while we have (70) and (71) for the lexical signs $Kim \triangleleft n \triangleright k$, $loves \triangleleft n \overset{*}{\backslash}(s \underset{*}{/} n) \triangleright \textsc{love}$ and $Mia \triangleleft n \triangleright m$:

(70) $y(z)(x)[x \to k, y \to \textsc{love}, z \to m] = \textsc{love}(m)(k)$

(71) $\langle f \,\text{`}\, \langle g \,\text{`}\, h \rangle\rangle \llbracket f \to Kim, g \to loves, h \to Mia \rrbracket =$
$f \llbracket f \to Kim, g \to loves, h \to Mia \rrbracket \langle g \,\text{`}\, h \rangle \llbracket f \to Kim, g \to loves, h \to Mia \rrbracket =$
Kim $\langle g \,\text{`}\, h \rangle \llbracket f \to Kim, g \to loves, h \to Mia \rrbracket =$
Kim $g \llbracket f \to Kim, g \to loves, h \to Mia \rrbracket \; h \llbracket f \to Kim, g \to loves, h \to Mia \rrbracket =$
Kim loves $h \llbracket f \to Kim, g \to loves, h \to Mia \rrbracket =$
Kim loves MIA

3 Catalan

4 English

5 Discourse Representation Theory

To be continued...

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